

Enhancing fourth-graders' fraction number line estimation using digital number lines

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ABSTRACT

This study investigated fourth-grade students' ability to estimate fractions on a bounded number line ranging from 0 to 1 as well as their views on using digital games in mathematics education. One hundred students completed two estimation tasks before and after an intervention involving three digital number line games over two teaching sessions. In task 1 (number-to-position – NP), students estimated the position of a given fraction on a number line, whereas in task 2 (position-to-number – PN), they estimated the fraction corresponding to a given position. Pre-test performance was moderate (57.9%) and improved significantly following the intervention (76.7%), with the highest post-test performance observed in task 2 (80.4%). In both tasks, students performed better with fractions smaller than one-half. Although participants reported some challenges related to the games, such as duration and mathematical difficulty, they indicated that the games supported their understanding of fractions. Additionally, a majority of students (64%) expressed interest in using digital games in mathematics learning. These findings suggest that digital number line games can enhance students' fraction estimation skills while promoting positive attitudes toward mathematics learning.

Keywords: number line estimation, digital games, fractions, primary school

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INTRODUCTION

The rapid development of digital technologies has significantly influenced educational practices, creating new opportunities for teaching and learning. The use of digital tools, including computers, smartphones, tablets, and educational applications, has been shown to support students in achieving their learning goals and enhancing their learning experiences (Newby et al, 2011). In mathematics education in particular, technology-based environments, especially digital games, have been found to increase student engagement, foster reasoning skills (Çankaya & Karamete, 2009), and contribute to the development of positive attitudes toward mathematics from an early age (Divjak & Tomic, 2011).

A central goal of mathematics education is the development of students' understanding of numerical magnitude. Although both children and adults often experience difficulties in interpreting and comparing numerical magnitudes, such understanding is essential for mathematical learning and achievement (Riconscente,

2013). Number line estimation tasks are widely used to assess students' conceptual understanding of numbers and their magnitudes (Koç, 2019; Soni & Okamoto, 2020).

Recent research has highlighted the potential of digital environments, particularly game-based learning, to support number line estimation and improve students' understanding of numerical magnitude (Braithwaite & Siegler, 2020; Fazio et al., 2016; Käser et al., 2013; Ninaus et al., 2017; Riconscente, 2013; Soni & Okamoto, 2020). Intervention studies indicate improvements in students' estimation performance on both whole and rational number tasks following the use of digital number line tools, while the engaging nature of such environments may further support confidence and achievement in mathematics (Kucian et al., 2011). However, most existing research has focused on whole numbers, with fraction-specific magnitude understanding in primary education remaining underexplored, particularly in bounded number line contexts. This study investigates primary school students' fraction estimation abilities using digital number line games and examines their effect on fraction magnitude understanding, aligning with curricula that emphasize

number line estimation as a key component of number sense and mathematical reasoning (Schneider et al., 2018).

THEORETICAL BACKGROUND

Number Line Estimation

Number line estimation refers to the process of translating a number into a spatial position on a number line or conversely, determining a numerical value corresponding to a given spatial position (Siegler et al., 2009). Although it is not frequently used or found in everyday contexts, number line estimation plays a central role in mathematics education (Andrews et al., 2022), as it supports the development of number sense in children (Zhu et al., 2017). From a cognitive perspective, number line estimation is considered an externalization of the mental number line, reflecting the way numerical magnitudes are internally represented and organized. Research suggests that children's representations of numerical magnitude typically develop from more logarithmic toward more linear structures with age and experience, indicating increasing precision in magnitude understanding. The number line is widely recognized as an effective representational tool for supporting numerical understanding and developing conceptual knowledge of numbers (Riconscente, 2013; Siegler et al., 2011). Furthermore, performance in number line estimation tasks has been shown to be a strong predictor of later mathematics achievement (Booth & Siegler, 2006; Hamdan & Gunderson, 2017; Schneider et al., 2018).

To examine individuals' number line estimation ability, researchers typically employ two types of tasks. In these tasks, participants are presented with a horizontal number line (Schneider et al., 2018) with two numbers marked at either end to define its range (e.g., from 0 to 10 or from 0 to 100). The first type, known as the number-to-position (NP) task, requires individuals to estimate the spatial position of a given number on the line (e.g., "Where is 28 approximately located?"). The second type, known as the position-to-number (PN) task, requires individuals to estimate the numerical magnitude corresponding to a specific position on the line (e.g., "Which number approximately corresponds to this point?").

Research shows that number line estimation performance improves with age and mathematical experience, reflecting the development of more efficient strategies and more accurate magnitude representations (Barth & Paladino, 2011; Slusser et al., 2013; Thompson & Opfer, 2010). Nevertheless, performance varies not only across ages but also within age groups, influenced by factors such as number size (small or large numbers), number type (whole or rational numbers), and task type (NP or PN tasks) (Desli, 2021).

Intervention Programs for Number Line Estimation

Prior research has shown that students' understanding of number magnitude and fraction representation can be supported through a range of instructional interventions. These include structured number line activities, explicit classroom instruction, and linear board games designed to foster numerical order and proportional reasoning (e.g., Siegler & Ramani, 2009). In such interventions, children typically engage in repeated placement or comparison tasks on bounded number lines, often supported by teacher feedback and guided discussion of numerical magnitude. In addition, instructional programs that explicitly focus on benchmark numbers, partitioning strategies, and spatial reasoning have been shown to improve students' number line estimation performance across different numerical ranges. For example, Hamdan and Gunderson (2017) found that paper-based number line training with second- and third-grade students not only improved estimation performance but also transferred to untrained fraction magnitude comparison tasks, highlighting the role of number line knowledge as a foundational component of fraction understanding. Overall, findings suggest that these approaches can enhance students' understanding of numerical magnitude, although improvements are sometimes task-specific and may not always transfer broadly across contexts.

While these non-digital interventions highlight the instructional value of number line-based activities, recent developments in educational practice have increasingly turned to digital technologies as a means of extending and enriching such learning experiences. In this context, teachers increasingly incorporate digital technologies into mathematics teaching, including digital number line games (Kiili et al., 2018). These environments provide interactive and engaging learning experiences that can increase student motivation and support more flexible engagement with mathematical concepts (Lunardon et al., 2023). From a learning perspective, digital number line games may support conceptual development by providing immediate feedback, enabling active manipulation of numerical representations, and facilitating the coordination of multiple representations of magnitude. Such features can promote self-regulation and support conceptual change in students' understanding of numbers.

Empirical studies have demonstrated the effectiveness of digital number line interventions across different age groups, from kindergarten through elementary school. For instance, Riconscente (2013) examined the impact of the digital game *motion math* on fifth-grade students' fraction learning using an experimental design in which students in the intervention group engaged with the game daily for short periods, while a control group received conventional instruction. The game required students to place fractions on a number line and provided immediate feedback on their responses. Similarly, Soni and Okamoto (2020) used *motion math* with fourth-grade students in tasks involving fraction comparison and estimation. Both studies reported

significant improvements in students' understanding of fractions, highlighting the potential of digital number line games to support rational number learning.

More recently, McMullen et al. (2024) developed the "number line elaboration and exploration" environment, which included two digital games designed to strengthen number line estimation and rational number understanding among 13-year-old students. Students in the intervention group used the games over a six-week period, whereas those in the control group received traditional instruction. In the "number trace" game, students estimated the position of fractions on a number line, while in "NanoRoboMath" they moved a nanorobot to a target position. The findings indicated that students who participated in the intervention demonstrated greater gains in rational number understanding than their peers in the control group. The authors attributed these improvements to interactive representations, which encouraged the use of multiple estimation strategies and supported a deeper understanding of numbers and number properties.

Overall, digital number line games provide interactive, feedback-rich learning environments that support students' understanding of numerical magnitude by promoting active engagement with number representations and facilitating more accurate spatial-numerical mappings. These features make them a promising instructional tool for strengthening number line estimation skills, particularly in relation to rational numbers such as fractions. Nevertheless, research shows that fractions remain a particularly challenging domain for primary school students (Demedts et al., 2024), further highlighting the need for instructional approaches that explicitly support the development of fraction magnitude understanding and number line estimation skills.

THE PRESENT STUDY

Although a growing body of international research has examined the use of digital games in mathematics education, relevant studies in the Greek educational context remain limited. Fractions are widely recognized as a challenging mathematical concept, with persistent misconceptions hindering students' understanding (e.g., Deringöl, 2019; Siegler et al., 2011; Xu et al., 2024), mainly due to their relational nature, as they represent ratios between quantities rather than discrete entities. Understanding fraction magnitude on a number line is a complex cognitive task that requires the coordination of proportional reasoning and spatial representation. Developing a robust understanding of fractions and their representation on the number line is therefore essential, as it provides a foundation for later success in mathematical domains such as ratios, percentages, and algebra (Koç, 2019; Riconscente, 2013; Siegler et al., 2011). Against this backdrop, the present study addresses a gap in the Greek literature while also contributing to the broader field of technology-enhanced mathematics education by providing insights into the potential of digital number line games to support students'

fraction understanding and numerical reasoning. Specifically, the present study aims, first, to examine the effect of a digital number line intervention on primary school students' ability to estimate fractions on a number line and, second, to explore students' views regarding the use of digital games in mathematics learning.

The following research questions guided the study:

1. What is the ability of children to estimate fractions on a number line before and after engaging with digital number lines?
2. Does children's fraction estimation performance differ according to the type of task (NP vs. PN)?
3. Does children's fraction estimation performance differ according to the size of the numbers (smaller Vs. larger than one-half)?
4. What are students' views regarding the use of digital games in mathematics teaching?

METHOD

Participants

The study was conducted in two phases, a pre-test and a post-test, with fourth-grade primary school students. A total of 106 students participated in the pre-test and 118 students in the post-test. For the purposes of the analysis, only data from the 100 students who participated in both phases were included. The final sample comprised 52 girls (52%) and 48 boys (48%).

Participants were fourth-grade students, as rational numbers are introduced progressively in the Greek primary mathematics curriculum from grade 3 onwards, making this grade appropriate for examining early fraction number line estimation skills. None of the participants had previously used digital number line games or received specific instruction in number line estimation beyond the regular curriculum. Students were recruited from seven public primary schools across different regions of Greece using convenience sampling, including both urban and rural settings, to enhance variability in socioeconomic and educational backgrounds. Participation was voluntary and required parental informed consent and school approval. All data were collected and analyzed anonymously to ensure confidentiality.

Data Collection – Research Instruments

This study employed a quantitative research approach within a quasi-experimental framework using a one group pre-/post-test design. This design enabled the examination of changes in students' performance before and after participation in the intervention (Bryman, 2016; Fraenkel et al., 2020). The independent variable was the instructional intervention based on the use of digital number line games, whereas the dependent variables were students' performance scores on the number line estimation tasks.

Task 1 - Number to Position Task (NP task)

Where is $\frac{4}{9}$ approximately located on the numberline?

**Task 2 - Position to Number Task (PN task)**

Which number approximately corresponds to this point?



Figure 1. Examples of NP and PN tasks (Source: authors' own elaboration)

For the purposes of the study, all participants were individually administered two number line estimation tasks, using a bounded number line ranging from 0 to 1, each consisting of 10 items. A high level of internal consistency was observed for the total of task items, as indicated by Cronbach's alpha ($\alpha = .861$). In task 1, NP task, fractions smaller than one were presented, and participants were asked to estimate their position on a number line by marking a vertical line at the point they considered most appropriate. In task 2, PN task, a point on the number line was marked by an arrow, and participants were asked to estimate the value of the fraction corresponding to that position (**Figure 1**). The inclusion of both task types allowed the examination of potential differences in estimation performance between NP and PN tasks.

To examine whether participants' performance on the number line was affected by the size of the numbers, both tasks included fractions smaller and larger than one-half ($\frac{1}{2}$). More specifically, each task consisted of five items with fractions smaller than one-half ($< \frac{1}{2}$) and five items with fractions larger than one-half ($> \frac{1}{2}$). To ensure a balanced distribution of fractions across the two tasks, the fractions used in the PN task were complementary to those used in the NP task; for example, $\frac{1}{4}$ in the NP task corresponded to $\frac{3}{4}$ ($1 - \frac{1}{4} = \frac{3}{4}$) in the PN task. Care was taken to avoid repetition of fractions between the two tasks, including the use of equivalent fractions. Finally, the items were arranged in a randomized order that was identical for all participants.

The same items were used in both the pre-test (**Appendix A**) and post-test (**Appendix B**). To reduce recall effects, fractions presented in the PN task during the pre-test were presented in the NP task during the post-test, and vice versa. For example, the first item of task 1 (NP) in the pre-test required participants to estimate the position of $\frac{1}{4}$ on the number line, whereas the corresponding item in the post-test required participants to estimate the position of $\frac{3}{4}$.

Lastly, to explore participants' views regarding the use of digital games in mathematics learning, a questionnaire was administered following the intervention (**Appendix C**).

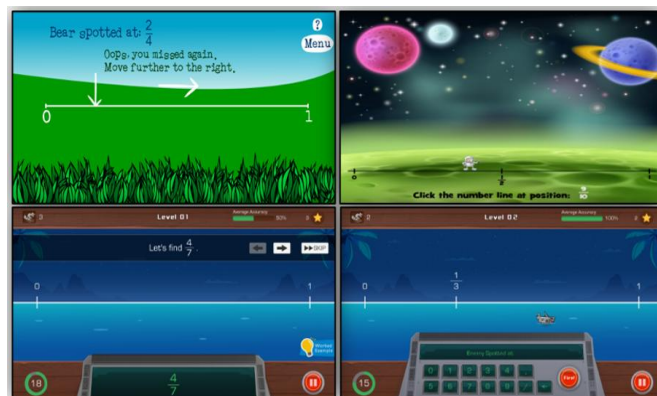


Figure 2. Examples of the digital number line games used in the intervention (<https://www.sheppardsoftware.com/math/fractions/animal-rescue/>; <https://www.cokogames.com/placing-fractions-on-a-number-line/>; <https://www.playpowerlabs.com/battleship-numberline-2>)

The questionnaire was administered in paper-and-pencil format and included four questions, with an equal number of open-ended and closed-ended items. The open-ended questions asked participants to express their views on digital number line games, focusing on elements they liked most and least. The closed-ended questions used a five-point Likert scale to examine students' perceptions of the use of digital games in mathematics learning.

Digital Number Line Games

Three digital number line games were used in the study: *animal rescue*, *astronaut fractions and decimals*, and *battleship numberline*. In all three games, students were required to identify or place fractions at appropriate positions on bounded number lines ranging from 0 to 1 and received immediate feedback on the accuracy of their responses (**Figure 2**). In *animal rescue*, students estimate the position of fractions on a number line in order to complete game-based challenges aimed at rescuing animals. A notable feature of this game is that the number line can be partitioned progressively into halves, quarters, sixths, and other equal intervals, allowing students to gradually develop an understanding of fractions and their locations on the number line. In *astronaut fractions and decimals*, students interact with a space-themed environment in which they place fractions on number lines to guide an astronaut's movement. Specifically, students click on the position they believe is correct, and when their estimate is sufficiently close to the target location, a rocket appears and carries the astronaut into space. In *battleship numberline*, students identify fractions on a number line to locate hidden targets within the game environment. Specifically, students estimate the position of fractions on the number line in order to drop a bomb and sink a ship. Unlike the other two games, *battleship numberline* is time-limited and provides students with opportunities to practice estimating the fractional value corresponding to a given spatial position on a number line (PN task).

The games were selected according to the educational game design criteria proposed by Bottino et al. (2007), ensuring their suitability for classroom implementation. Specifically, all three games incorporate progressive levels of difficulty, provide corrective support when errors occur, and offer feedback to facilitate students' fraction estimation on the number line. In addition, the games include age-appropriate visual and auditory features, such as graphics, colors, and sound effects, which were considered important for maintaining students' engagement and motivation during the intervention.

Procedure

All participants were assessed individually in a quiet place within their school to minimize distractions and maintain concentration during both the pre- and post-test. Children were informed that their performance on the tasks would not affect their mathematics grades. Prior to the administration of the tasks, detailed instructions were provided, and an example item for each task was demonstrated on the classroom board to ensure that participants understood the task requirements. Following the practice examples, no additional feedback was given. The pre-test took approximately 35-40 minutes to complete.

Two weeks after the pre-test, students engaged with the digital number line games across two teaching sessions, with a total duration of 90 minutes. All games were played individually in the school computer laboratory, with students spending approximately 30 minutes on each game. To avoid potential fatigue effects, the post-test and questionnaire were administered on the day following the intervention. The post-test required approximately 20-25 minutes to complete, while the questionnaire required approximately 15 minutes.

At both the pre- and post-test, participants were provided with a 20-page booklet, with ten pages containing the NP items and ten pages containing the PN items. Each page included the task instructions and a 25-cm bounded number line ranging from 0 to 1, centered on the page.

Data Coding

In both task 1 (NP) and task 2 (PN), a lenient scoring method was used to assess participants' performance, consistent with previous number line estimation studies (e.g., Booth & Siegler, 2006; Slusser et al., 2013) for distinguishing success from less successful estimates. More specifically, estimates falling within a tolerance interval equal to 20% of the total number line length were classified as correct. Consequently, responses located within $\pm 10\%$ of the exact target value were considered successful estimates. For statistical analyses, each correct response was assigned a score of 1 and each incorrect response a score of 0, yielding a maximum score of 20 across the two tasks (10 points per task).

In task 1 (NP), success was determined on the basis of the physical length of the number line. As each number line measured 25 cm, the tolerance interval of 20%

Table 1. Mean number of successful estimations in pre- and post-test tasks

Test		M	SD	Minimum	Maximum
Pre-test	Task 1 – NP	5.64	2.81	1	10
	Task 2 – PN	5.94	3.09	0	10
	Overall	11.58	5.08	1	20
Post-test	Task 1 – NP	7.30	2.07	4	10
	Task 2 – PN	8.04	2.45	2	10
	Overall	15.34	4.12	6	20

Note. M: Mean & SD: Standard deviation

corresponded to 5 cm in total (± 2.5 cm around the exact position). Therefore, estimates placed within 2.5 cm to the left or right of the target location were coded as correct. For example, the exact position of $\frac{2}{3}$ on a 25-cm number line is 16.7 cm; therefore, responses falling within the acceptable interval (14.2-19.2 cm) were classified as correct. Similarly, in task 2 (PN), success was determined according to the numerical range of the number line. Because the number line ranged from 0 to 1, the tolerance interval of 20% corresponded to a total range of 0.20 (± 0.10 around the target value). Accordingly, responses to 0.10 above or below the target fraction were considered correct. For example, for a target value of $\frac{1}{3}$, responses between 0.23 and 0.43 were considered correct.

To examine students' tendencies to overestimate or underestimate, responses from both tasks were additionally coded. In task 1 (NP), responses placed to the right of the exact position were coded as 1 (overestimation), responses to the left were coded as 2 (underestimation), and responses at the exact target position were coded as 3 (accurate response). Similarly, in task 2 (PN), responses greater than the target fraction were coded as 1 (overestimation), responses smaller than the target fraction were coded as 2 (underestimation), and responses equal to the target value were coded as 3 (accurate response).

RESULTS

Main Results

Table 1 provides an overview of the mean scores, standard deviations, and minimum and maximum values for the tasks used in this study. The results indicate that participants' performance on the two tasks was comparable at pre-test and substantially lower than their performance on the same tasks at post-test. Performance on each task exhibited adequate variance, with no evidence of floor or ceiling effects.

The overall participants' performance at pre-test was moderate, with a success rate of approximately 58%. A statistically significant improvement was observed at post-test ($t[99] = -6.600$, $p < .001$), with success rates exceeding 76% following the use of the digital number line games. This finding was also revealed when the analysis was carried out separately for each task ($t[99] = -4.935$, $p < .001$) and ($t[99] = -5.770$, $p < .001$, for task 1 and task 2, respectively). No statistically significant gender differences were found, with

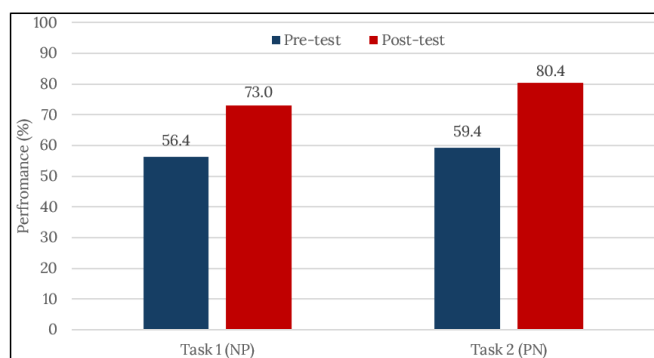


Figure 3. Percentage of correct responses by type of task in the pre- and post-test (Source: authors' own elaboration)

boys and girls achieving similar percentages of correct responses at both pre-test ($t[98] = 2.681, p = .145$) and post-test ($t[98] = 1.402, p = .670$).

Rates of Correct Responses by Type of Task (NP and PN)

No statistically significant differences were observed between participants' performance on the two tasks during the pre-test ($t[99] = -.701, p = .243$). Specifically, performance in task 1 (56.4%) was similar to performance in task 2 (59.4%). In contrast, the same analysis conducted for post-test revealed statistically significant differences between the two tasks ($t[99] = -2.764, p < .01$), with higher performance in task 2 (80.4%) than in task 1 (73%), indicating that participants were more successful when estimating the value of a fraction corresponding to a given position on the number line than when estimating the position of a fraction on the number line. This task-related difference was observed only in the post-test, suggesting that the improvement following the use of digital games was more pronounced in the PN task. **Figure 3** shows these differences.

Although success rates were higher in task 2, the tasks also differed in the patterns of participants' estimation responses. Specifically, as shown in **Table 2**, in the NP task, participants tended to underestimate fractions, placing them to the left of their exact positions on the number line in both the pre- and post-test. In contrast, in the PN task, participants' estimates during the pre-test were more balanced, including both over- and underestimations,

Table 3. Mean number ($mx = 5$) of successful estimations (and standard deviation) by type of task and number size in the pre- and post-test

Number size	Mean (standard deviation)			
	Pre-test		Post-test	
	Task 1- NP	Task 2 - PN	Task 1- NP	Task 2 - PN
Small numbers	3.14 (1.62)	3.48 (1.66)	4.10 (1.01)	3.86 (1.49)
Large numbers	2.50 (1.57)	2.46 (1.81)	3.26 (1.46)	4.18 (1.38)

whereas in the post-test overestimations were more frequent. Notably, participants also demonstrated high rates of accurate estimation in the PN task, with 20.6% correct responses in the pre-test and 30.2% in the post-test. Overall, these findings suggest that task 2 (PN) was associated with more accurate estimation performance than task 1 (NP).

Rates of Correct Responses by Number Size

Statistically significant differences were found in children's performance depending on fraction size in both the pre- and post-test ($t[99] = 5.143, p < .001$ and $t[99] = 2.201, p < .05$, respectively). Children achieved significantly higher scores on items containing fractions smaller than one-half (66.2% and 79.6% in the pre- and post-test, respectively) compared to items containing fractions larger than one-half (49.6% and 73.8% in the pre- and post-test, respectively). When further analyses were conducted for each task and testing phase, the results were mixed. Significant differences in participants' performance between small-fraction and large-fraction items were found in task 1, at both the pre-test and the post-test ($t[99] = 3.027, p < .01$ and $t[99] = 4.489, p < .001$, respectively). In task 2, significant differences were observed at pre-test ($t[99] = 4.590, p < .001$) but not at post-test ($t[99] = -1.518, p = .068$). Specifically, in the pre-test, participants performed better on items with fractions smaller than one-half in both tasks (62.8% and 69.6% for task 1 and task 2, respectively). However, whereas the effect of fraction size persisted in task 1 at post-test, performance in task 2 became comparable for small and large fractions (77.2% and 83.6%, respectively). **Table 3** illustrates the interaction between task type and fraction size in both the pre- and post-test.

Although success rates were significantly higher for items involving small fractions than for those involving large

Table 2. Percentage of estimates in the pre- and post-test by type of task and number size

Test	Task	Type of estimations		
		Overestimation	Underestimation	Accurate
Pre-test	Task 1	35.4%	62.6%	2.0%
	Small	46.0%	52.4%	1.6%
	Large	24.8%	72.8%	2.4%
	Task 2	40.4%	39.0%	20.6%
	Small	45.2%	29.6%	25.2%
	Large	35.6%	48.4%	16.0%
Post-test	Task 1	43.0%	54.4%	2.6%
	Small	41.6%	55.6%	2.8%
	Large	44.4%	53.2%	2.4%
	Task 2	38.6%	31.2%	30.2%
	Small	44.0%	25.2%	30.8%
	Large	33.2%	37.2%	29.6%

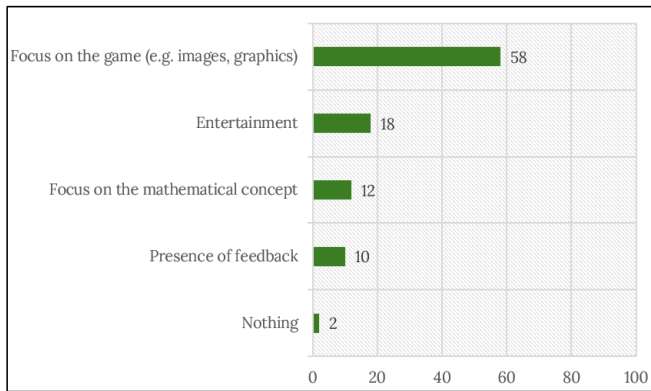


Figure 4. Frequency of participants' responses to "What I liked most about the games?" (Source: authors' own elaboration)

fractions, differences between number-size items were also reflected in the patterns of participants' estimates. Overall, children exhibited a size-dependent bias, tending to overestimate smaller values and underestimate larger values in both tasks and across both testing phases. For example, in the NP task, almost 75% of the children placed $\frac{2}{3}$ to the left of its correct position on the number line during the pre-test, with estimates clustering around lower numerical values (approximately 0.4). A similar pattern was observed for $\frac{1}{3}$, in the post-test, where most children (about 70%) overestimated its position on the number line. When estimating smaller fractions, such as $\frac{2}{10}$, approximately 60% of children placed the value at higher numerical positions (e.g., around $\frac{4}{10}$) during the pre-test. In the PN task, the same size-related bias was evident but less pronounced. For instance, in the pre-test, 52% of children overestimated the value corresponding to the position of $\frac{2}{5}$, while in the post-test, 42% overestimated the value for $\frac{3}{7}$. Conversely, underestimations were observed for larger fractions: 58% of children underestimated $\frac{5}{9}$ and 54% underestimated $\frac{5}{6}$ in the pre- and post-test, respectively.

Participants' Views on Digital Number Line Games

After the post-test, participants completed a questionnaire examining their views on the use of digital number line games. The questionnaire included two open-ended questions exploring what students liked most and least about the games, as well as two closed-ended Likert-scale questions focusing on perceived learning benefits and students' preferences for learning fractions through digital games. Responses to the open-ended questions were analyzed using a categorization procedure to identify emerging themes.

The participants' responses to the question "What I liked most about the games ..." were analyzed and grouped into five categories. Most participants (58%) highlighted features related to the games' narrative elements and design, including graphics (e.g., rescuing animals from a cage), visual design, and music. A smaller proportion (18%)

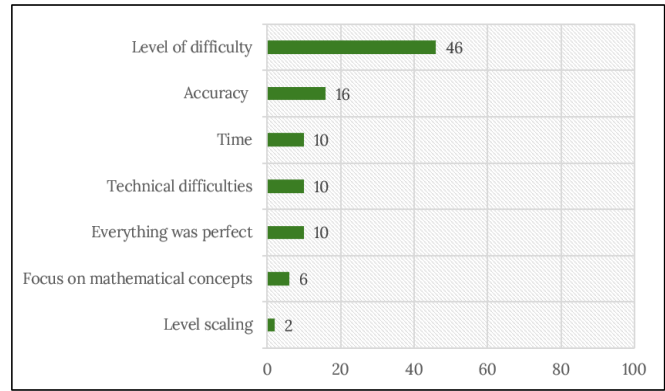


Figure 5. Frequency of participants' responses to "What I liked least about the games?" (Source: authors' own elaboration)

emphasized the entertainment value and fun of the games without referring to specific features. Other responses focused on the mathematical content, particularly fractions and estimation on the number line (12%), or on the presence of feedback, including examples and guidance provided when participants were unable to complete a task. A few participants provided non-specific responses without identifying particular aspects of the games they liked. **Figure 4** presents the frequency of participants' responses across these categories.

Regarding the second question (**Figure 5**), "What I liked least about the games ...," nearly half of the participants (46%) reported that the level of difficulty made the games tiring and less enjoyable. A further 16% indicated that the requirement for high accuracy in placing fractions on the number line negatively affected their experience, as progression through the levels depended on precise responses. Other responses referred to limited time available to complete tasks (10%), a feature unique to the third game (*battleship numberline*), as well as difficulties related to the mathematical content (10%), such as fraction estimation and working with larger numbers. A small number of participants reported technical issues, including slow internet connections or interruptions, while others identified the large number of levels as a factor that made the games tiring and demanding. Finally, a few participants reported no negative aspects of the games.

Furthermore, responses to the statement "I felt that I understood fractions and their position on the number line" indicate that approximately two-thirds of participants (64%) reported a positive perception of their understanding of fractions after engaging with the digital games. This is consistent with the significantly higher performance of the children on all items in the post-test (**Figure 1**). The improvement in performance may be partly facilitated by a strategy spontaneously developed by some participants during gameplay, in which they used their fingers to partition the digital number line into segments to estimate the position of each fraction. Participants applied this strategy across items in both tasks during the post-test, resulting in more accurate estimates, particularly in task 2

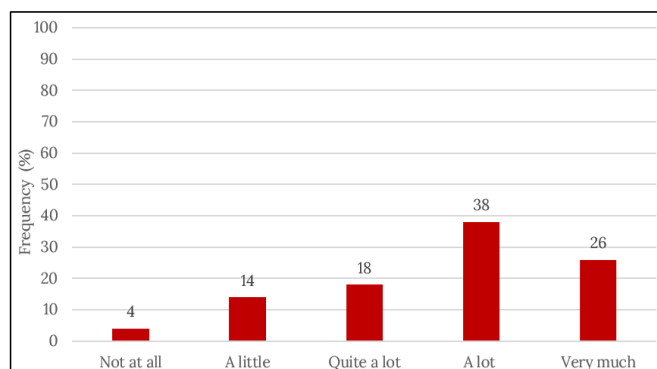


Figure 6. Frequency of participants' responses to "I felt that I understood fractions and their position on the number line" (Source: authors' own elaboration)

(PN). Although the analysis of participants' strategies was not an objective of this study, this behavior suggests that some children independently developed and applied useful estimation strategies that may have supported their improved performance. **Figure 6** presents these data.

Finally, in response to the statement "I would like mathematics to be taught through computer games", 12% of participants indicated that they did not wish to learn mathematics in this way, as shown in **Figure 7**. This suggests that the majority of children are receptive to the integration of digital games in the classroom.

DISCUSSION AND CONCLUSIONS

The present study aimed to examine the effect of digital number line games on students' ability to estimate fractions on a bounded number line and to explore their views on the use of digital games in mathematics teaching. Four main findings emerged from the analysis.

First, students improved significantly after engaging in digital games, with success rates increasing from 57.9% on pre-test to 76.7% on post-test. This finding is consistent with previous research demonstrating that digital number line environments can support students' understanding of rational numbers and improve estimation accuracy (Fazio et al., 2016; Kiili et al., 2018; Riconscente, 2013). Despite well-documented difficulties in working with rational numbers, particularly fractions (Braithwaite & Siegler, 2021; Demedts et al., 2024; Deringöl, 2019), the interactive nature of digital number lines appears to support number sense development by making magnitude relations more visible and manipulable, thereby facilitating conceptual understanding.

Second, differences were also observed between task types. While performance on NP and PN tasks was comparable at pre-test, a divergence emerged at post-test, with higher success rates in the PN task. This pattern contrasts with findings reporting greater difficulty in PN tasks (Iuculano & Butterworth, 2011). One possible explanation is that interaction with digital number lines may have supported the development of informal partitioning

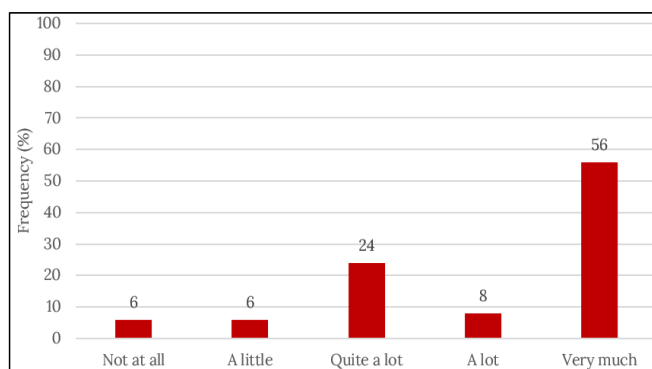


Figure 7. Frequency of participants' responses to "I would like mathematics to be taught through computer games" (Source: authors' own elaboration)

strategies, whereby students used reference points to mentally divide the number line into equal segments, facilitating more accurate estimates. Such strategies may have been particularly beneficial in PN tasks, where reverse mapping from spatial position to numerical value is required. Although strategy use was not directly assessed, this interpretation warrants further investigation into how digital environments shape estimation processes in tasks involving PN estimations.

Third, a consistent effect of number magnitude was also observed. Students performed better on fractions smaller than one-half (e.g., $\frac{1}{6}$) than on larger fractions in both the pre- and post-test. This finding aligns with Siegler et al. (2011), who reported higher accuracy in number line estimation tasks for smaller fractions relative to larger ones, reflecting systematic difficulties in representing larger fractional magnitudes on number lines. However, the post-test results suggest a reduction in this gap, mainly attributable to improved performance on larger fractions, particularly in the PN task. This pattern may indicate that digital number line practice supports more balanced representations of fractional magnitude.

Beyond accuracy, differences in response patterns were evident. In the NP task, underestimations dominated regardless of number size in both the pre- and post-test. In contrast, the PN task showed a more balanced distribution of over- and underestimations at pre-test, which shifted towards overestimation at post-test. These patterns suggest that task type influences estimation strategies and error tendencies, potentially reflecting differences in how spatial and symbolic representations are processed in digital environments, highlighting the need for further research into the cognitive factors that influence children's number line estimation skills.

Finally, the majority of students expressed positive views about the use of digital number line games in mathematics instruction. Nearly two-thirds of students (64%) reported that the games helped them understand fractions and their position on the number line, a perception consistent with the observed improvements in performance. The aspects most appreciated were the visual and narrative features of

the games, as well as their engaging and game-like nature, while only a small proportion of students expressed negative views. These findings align with research highlighting the motivational role of game-based learning environments in mathematics (Divjak & Tomic, 2011; Fokides, 2018; Sun et al., 2021). Overall, these promising results underscore the potential of digital games as effective tools for supporting mathematics learning, fostering positive dispositions towards mathematics as well as encouraging students' acceptance of innovative instructional approaches in mathematics.

As with any research study, certain limitations regarding the generalizability of the findings should be acknowledged. First, students' exposure to the digital number line games was relatively brief, consisting of only two teaching sessions, which limits conclusions regarding long-term effects. Second, although the sample included students from different schools, broader socioeconomic and regional representation would enhance the robustness of the findings. Third, strategy use was inferred rather than directly measured, suggesting an important direction for future research. Finally, the findings are limited to the specific digital number line games used in the intervention. As digital mathematics games vary considerably in their design characteristics, the positive effects observed in this study may not generalize to games that provide different forms of feedback, levels of challenge, or instructional support.

In summary, the findings suggest that short-term engagement with digital number line games can enhance students' ability to estimate fractions on a bounded number line while also promoting positive attitudes towards mathematics learning. The observed improvements in number line estimation accuracy indicate that digital number line environments may serve as valuable tools for supporting students' understanding of fraction magnitude and the development of number sense. Future research could extend this work by examining the long-term effects of digital number line interventions, investigating the estimation strategies students employ when interacting with digital number lines, and exploring how such environments can be effectively integrated into classroom practice. Given the increasing role of digital technologies in mathematics education, the present findings also highlight the importance of supporting teachers in selecting and implementing appropriate digital resources and in developing the pedagogical content knowledge required to use digital number line tools effectively, a need that has been emphasized in previous research (Loong & Herbert, 2018; Perienen, 2020). Expanding this line of research may contribute to a deeper understanding of how digital environments can support number line estimation and fraction learning in primary mathematics education.

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AI statement: The authors stated that no generative AI or AI-based tools were used in writing this paper.

Declaration of interest: Authors declared no competing interest.

Data availability: Data generated or analyzed during this study are available from the authors on request.

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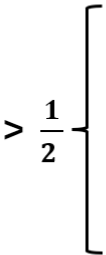
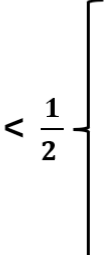
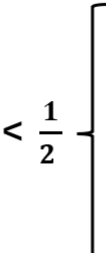
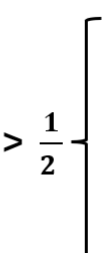
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Task 1 (NP):		Task 2 (PN):	
Number line	Number-to-position	Position-to-number	
$\left\{ \begin{array}{l} < \frac{1}{2} \end{array} \right.$	$\frac{1}{4}$	$\left\{ \begin{array}{l} > \frac{1}{2} \end{array} \right.$	$\frac{3}{4}$
	$\frac{2}{6}$		$\frac{4}{6}$
	$\frac{3}{7}$		$\frac{4}{7}$
	$\frac{4}{9}$		$\frac{5}{9}$
	$\frac{2}{10}$		$\frac{8}{10}$
$\left\{ \begin{array}{l} > \frac{1}{2} \end{array} \right.$	$\frac{2}{3}$	$\left\{ \begin{array}{l} < \frac{1}{2} \end{array} \right.$	$\frac{1}{3}$
	$\frac{6}{8}$		$\frac{2}{8}$
	$\frac{3}{5}$		$\frac{2}{5}$
	$\frac{5}{6}$		$\frac{1}{6}$
	$\frac{7}{10}$		$\frac{3}{10}$

APPENDIX B: POST-TEST ITEMS

Number line	Task 1 (NP): Number-to-position	Task 2 (PN): Position-to-number	
	$\frac{3}{4}$ $\frac{4}{4}$ $\frac{4}{6}$ $\frac{4}{7}$ $\frac{5}{9}$ $\frac{8}{10}$		$\frac{1}{4}$ $\frac{2}{6}$ $\frac{3}{7}$ $\frac{4}{9}$ $\frac{2}{10}$
	$\frac{1}{3}$ $\frac{2}{8}$ $\frac{2}{5}$ $\frac{1}{6}$ $\frac{3}{10}$		$\frac{2}{3}$ $\frac{6}{8}$ $\frac{3}{5}$ $\frac{5}{6}$ $\frac{7}{10}$

APPENDIX C: QUESTIONNAIRE ABOUT THE DIGITAL NUMBER LINE GAMES

1. What I liked **most** about the games was ...:

2. What I liked **least** about the games was ...:

3. I felt that I **understood** fractions and their position on the number line (circle the option that best describes you).
Not at all A little Quite a lot A lot Very much

4. I would like **mathematics to be taught through computer games** (circle the option that best expresses your opinion).
Not at all A little Quite a lot A lot Very much