Board Games and Mathematics: A Winning Strategy for Teaching Rational Numbers

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Abstract: The use of games in educational context has been widely recognised as an effective strategy for making learning more engaging and meaningful. Educational games create a dynamic environment where students not only consolidate academic knowledge but also develop soft skills such as teamwork, decision-making, and communication. In mathematics education, where student motivation is often a major concern, the incorporation of gamification strategies has shown a very positive impact on learning. Through playful challenges, students are encouraged to apply mathematical concepts in a practical and interactive way, increasing their engagement and improving their understanding of the subject matter. Moreover, the use of games in mathematics education extends beyond reinforcing curricular content. It also helps foster a more positive attitude towards the subject. This paper presents a study which explores the use of non-digital games as a pedagogical strategy in the teaching and learning of rational numbers in primary school. The main objective was to assess the effectiveness of non-digital board and card games as a teaching strategy for non-negative rational numbers among Year 5 students. The methodology adopted was a qualitative case study with quantitative statistical analysis, involving the implementation of three physical board/card games in three classes. Data collection techniques included surveys, direct observation by the teacher-researcher, and analysis of students' written work produced during gameplay. This study provides significant contributions, namely expanding knowledge on the effectiveness of non-digital games in mathematics education, offering evidence of their use as a pedagogical tool, and presenting a model that can be replicated and adapted by other educators. The results suggest that non-digital board and card games can be an effective strategy for teaching non-negative rational numbers, particularly due to increased student motivation, positive perceptions of mathematics, and improvements in self-confidence, self-esteem, willingness to overcome difficulties, and the development of social and collaborative skills.

Keywords: Educational non-digital games, Motivation, Mathematics education, Game-Based learning

1. Introduction

In recent years, the use of games as pedagogical strategies has gained prominence in educational contexts, particularly in mathematics education. Research has shown that educational games make learning more interactive, engaging, and effective by fostering the assimilation of complex concepts and encouraging active student participation (Gee, 2003; Prensky, 2003). These tools not only enhance conceptual understanding but also promote the development of collaborative and social skills essential in school environments (Johnson et al., 2011).

Researchers such as McGonigal (2011) argue that games have strong potential to motivate and engage people, suggesting they can be used to solve real-world problems and enhance personal and professional skills. Whitton (2014) emphasises that games support learning by tapping into players' intrinsic motivation. Schell (2019) highlights the importance of thoughtful game design—both for education and entertainment—stressing that user experience should be intuitive, enjoyable, and motivating. He also notes that elements such as narrative, mechanics, and feedback must be carefully planned, and that games should be adaptable to individual needs, allowing learners to progress at their own pace. Altogether, these authors see games as versatile and effective tools to address current educational and developmental challenges.

Didactic games are specifically designed to teach particular curriculum content, with clear learning objectives and structured activities aimed at deepening students' understanding of a subject (Kapp, 2012). In contrast, pedagogical games have a broader focus on overall student development, targeting emotional, social, and behavioural skills, and promoting general competencies such as critical thinking, problem-solving, collaboration, and creativity (Gee, 2003). The main distinction lies in their purpose: didactic games focus on content knowledge, while pedagogical games emphasise holistic skill development. Given the dual focus of the games in

this study—on both content and competencies—the term "educational games" will be used throughout the paper.

2. Educational Games in Mathematical Education

Game-based learning has long been recognized for its ability to promote motivation, problem-solving, and critical thinking. In mathematics—a subject often associated with high levels of anxiety and low engagement—the use of games presents a promising strategy for transforming the classroom into a more inclusive and dynamic learning space (Malone and Lepper, 1987; Vankúš, 2021).

According to the Portuguese Mathematics Curriculum (ME/DGE, 2021), learning activities should be mathematically rich and intellectually challenging, encouraging students to construct their own knowledge. In this context, educational games can foster logical reasoning, strategic thinking, and greater engagement. As noted by several researchers (Grando, 2000; Debrenti, 2024), games can also reduce maths anxiety, making learning more accessible and enjoyable for all students.

The literature (Bezerra, 1962; Grando, 1995; Kishimoto, 1998) shows that when games are used pedagogically, they enhance student motivation and support the development of key skills necessary for learning mathematics. These skills include strategic analysis, the anticipation and validation of results, critical reflection on actions, and the ability to attribute meaning to calculations. Therefore, it is essential for teachers to create a classroom environment that fosters logical reasoning through active teaching methodologies. In such an approach, students take a central role in the learning process, while the teacher acts as a facilitator of stimulating and effective experiences. Within this context, games emerge as ideal teaching tools, as they capture students' interest and engagement.

Board and card games, in particular, offer tactile and social experiences that complement digital resources. Espinoza-Espinosa et al. (2022) highlight several key benefits of physical board and card games for learners of all ages. These include fostering social interaction, which helps develop communication, cooperation, and conflict resolution skills (Gobet et al., 2004); supporting motor development through physical movement and coordination (Nelson et al., 2015); enhancing cognitive stimulation by encouraging strategic thinking and problem-solving (Ferguson, 2007); offering sensory immersion through visually, tactilely, and auditorily engaging components (Whitebread, 2012); and promoting inclusion and accessibility, as these games can be adapted for players with different abilities and needs (Koster, 2013).

Erşen and Ergül (2022) concluded that game-based learning in mathematics significantly enhances student engagement and motivation while also deepening conceptual understanding. However, their study emphasises that the effectiveness of games depends largely on their alignment with curriculum objectives and thoughtful integration into instructional planning.

Taking all this into account, the first author of this study, under the supervision of the remaining authors, developed three non-digital games for teaching rational numbers to Year 5 students, which formed the basis of her master's thesis (Hilário, 2024). The games were inspired by two Italian researchers, Paola Morando and Maria Spreafico, who have extensive experience in designing and implementing didactic games across a wide range of educational levels (from primary school to university) and in diverse educational contexts—both formal, such as schools and prisons, and informal, such as museums and botanical gardens (La Fortuna, Morando and Spreafico, 2022; Morando and Turconi, 2022; Morando and Spreafico, 2023).

This paper explores the pedagogical use of these games, with the main objective being to assess whether they could positively influence student motivation, support collaborative and interactive learning, and improve the understanding of mathematical concepts. The games were implemented, and data was collected and analysed to evaluate the outcomes.

3. Methodology

This study employed a qualitative case study approach, complemented by quantitative data analysis (Yin, 1994).

The main research questions were:

- Can non-digital board/card games enhance student motivation and engagement in learning rational numbers?
- Do such games contribute to a better understanding of mathematical content?

The objectives were:

- To design and implement non-digital games targeting rational numbers;
- To analyse the pedagogical impact of these games;
- To assess students' perceptions and learning outcomes.

Three original non-digital games were designed and implemented in Year 5 classes during the 2023/2024 school year. The study involved a total of 84 students, aged 10–11, all enrolled in the fifth year of basic education. These students were distributed across three separate classes, each comprising approximately 28 students. The school is part of the Portuguese public education network in the Lisbon district. The games were implemented during regular mathematics lessons, ensuring integration with the official curriculum.

Three primary methods were used for data collection:

- *Questionnaires*: Administered before and after the intervention to gauge perceptions and attitudes.
- *Classroom Observations*: Conducted by the teacher-researcher to record behaviours and interactions.
- *Student Work*: Analysis of written records produced during gameplay, along with photographs to assess students´ learning outcomes.

Due to space constraints, this paper will only address the first research question.

Quantitative data were analysed using Excel, generating bar and pie charts to illustrate trends. Qualitative data were interpreted thematically to highlight recurring patterns and insights.

4. Description of the Educational Games Developed

The games — Maths Twins, Tartarugas, Cavalos-Marinhos e Polvos (Turtles, Seahorses and Octopuses), and Caça ao Tesouro na Ilha da Matemática (Treasure Hunt on Maths Island) — were planned to align with the learning goals outlined in the Portuguese mathematics curriculum regarding non-negative rational numbers. Each game was developed with attention to simplicity, clarity, curricular integration, and active student participation. Simultaneously, the games were designed to be varied in nature, using different materials and mechanics. They not only cover different aspects of the topic addressed, but also contribute to achieve different learning goals, ranging from specific concepts (such as the use and meaning of percentages) to critical thinking, mathematical communication, and problem solving.

4.1 Maths Twins

Maths Twins is a memory-based card game designed to deepen students' understanding of multiplication and division involving decimal and fractional representations of non-negative rational numbers. The mechanics of matching equivalent expressions aim to support mental calculation, flexible thinking, and concept equivalence. Timed play and collaborative group structure foster both motivation and teamwork.

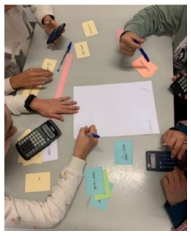
The version used in this study has the following characteristics:

- *Learning Topics*: Decimals, fractions, multiplication and division, mental calculation, and multiple representations.
- *Learning Goals*: Carry out calculations involving decimals and natural numbers; relate multiplication and division by 10, 100, and 0.1; interpret mathematical expressions in various formats.
- *Materials*: A set of 28 cards per group (14 matching pairs with equivalent expressions), paper, pencils, calculators, and a projector for teacher demonstration.
- *Game Objective*: Identify the greatest number of "maths twin" pairs—cards with expressions yielding the same result.
- *Gameplay*: Students work in teams of 3–4. Each team receives a deck of 28 cards and has 15 minutes to match as many equivalent expression pairs as possible. The competitive aspect and time constraint encourage engagement, group collaboration, and development of mental calculation skills. Assistance using calculators or written algorithms is allowed to ensure inclusivity.

This game can be adapted to various content areas and played in different ways. For instance, Pais and Hall (2024) describe three versions of gameplay using a deck addressing measurement units.

Figure 1 shows some examples of the expressions found on the cards and two photos of the students playing the game.

$2023 \div 0,01$	$0,001 \times 2023$	$2023 \times 0,01$
$4 \times 25 \times 2024$	$\frac{1}{100} \times 2024$	10×2024



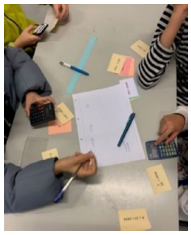


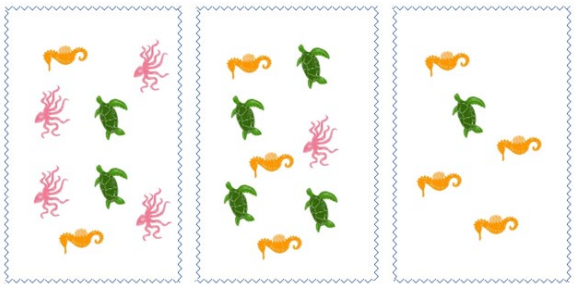
Figure 1: Maths Twins: examples of card contents and photos of the gameplay

4.2 Turtles, Seahorses and Octopuses (Tartarugas, Cavalos-Marinhos e Polvos)

This game is an adaptation of *Caterpillars and other animals* developed by La Fortuna and Morando (2022). It was tailored to help Year 5 students explore percentages, fractions, and decimals through logical reasoning. The activity engages students in identifying relationships among quantities represented in various forms (fractions, decimals, percentages). The use of illustrated animal cards, coupled with mathematical conditions, provides a visual and engaging way to interpret symbolic information, thereby encouraging analytical thinking, mathematical communication and strategic decision-making.

- *Learning Topics*: Percentages, fractions, decimals, multiple representations, and symbolic mathematical language.
- *Learning Goals*: Establish connections between fractional, decimal, and percentage representations; apply these representations in problem-solving; use mathematical communication.
- *Materials*: A set of 26 illustrated cards with animal representations (see Figure 1 for some examples) and another set of 36 cards with mathematical conditions (e.g., "Turtles represent 50% of the total," or "The number of turtles is 25% of the number of octopuses.").
- *Game Objective:* Identify cards that meet specific conditions regarding the quantities of animals (turtles, seahorses, octopuses) based on percentage clues provided.
- *Gameplay*: Players play in groups of two teams of two students each. At each table, six animal cards are placed face up, while the rest form a face-down draw pile. Condition cards are also placed in a separate face-down pile. Teams take turns drawing one condition card and collecting all face-up animal cards that meet the condition (collected cards act as points). Each time an animal card is taken, it is immediately replaced from the face-down pile to maintain six face-up cards. If no animal cards satisfy the condition, the team passes its turn.
- When the condition pile ends, the team with the greatest number of points wins.

Figure 2 shows some examples of animal cards and a photo of students playing the game.



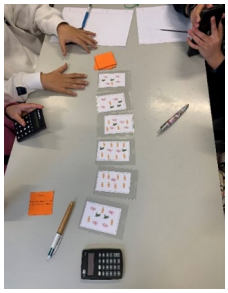


Figure 2: Turtles, Seahorses and Octopuses: examples of cards and photos of the gameplay

4.3 Treasure Hunt on Maths Island (Caça ao Tesouro na Ilha da Matemática)

Inspired by treasure hunt activities and classic educational games involving maps, this original game was developed by the first author of this paper to explore fractions, equivalences, and problem-solving with rational numbers. Designed as a map-based problem-solving adventure, this game integrates narrative with mathematical challenges, requiring students to solve fractional problems to navigate through a graph. The goal is to promote critical thinking, sequencing, and application of knowledge in context, while encouraging collaboration and persistence.

- *Learning Topics*: Fractions, decimals, equivalence, estimation, and rounding.

- *Learning Goals*: Identify equivalent fractions, solve word problems using rational numbers, and strengthen understanding through graph-based reasoning.
- *Materials*: A treasure map with a graph, instructions sheet, 9 challenge cards (one for each graph edge), hint cards (one for each vertex), and blank squared paper.
- *Game Objective*: Follow a path across the island by solving a series of mathematical challenges, ultimately revealing a hidden message (the treasure).
- *Gameplay*: Students play in teams of 3-4 members each. Each team receives all the materials. They must interpret the challenge cards and solve problems to determine the correct path on the graph (following the minimum distance edge at each vertex). Each correct solution advances the team closer to uncovering the final message.

The game emphasizes critical thinking, collaborative problem-solving, and application of mathematical concepts in context. Figure 3 shows the map of the game.

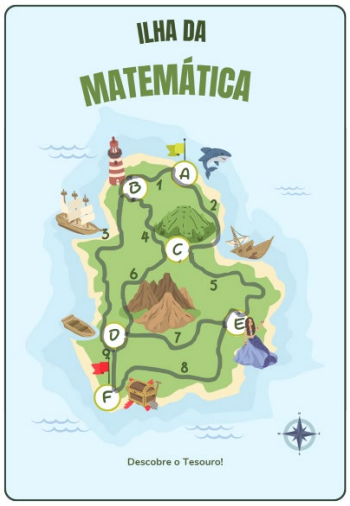


Figure 3: Treasure Hunt on Maths Island: map

5. Results and Analysis of Questionnaire Data

Each game was implemented in three Year 5 classes, following a structured pedagogical approach and adapted based on real-time classroom dynamics and student responses.

In *Maths Twins*, students worked in groups of four, applying mental and calculator-assisted strategies to identify matching "pairs of cards. Early observations showed that the initially planned game time was insufficient for both problem-solving and strategy development, leading to extended playtime in subsequent sessions. Students adapted quickly by employing whispering strategies to avoid revealing answers and to optimise their internal group coordination.

In Turtles, Seahorses, and Octopuses, students were tasked with matching marine animal image cards to condition cards involving percentages. The game effectively reinforced the link between different representations of rational numbers (fraction, decimal, percentage). Strategic use of calculators allowed students with varying skill levels to participate equally and remain engaged.

Treasure Hunt on Maths Island presented a narrative-based challenge where teams navigated a map by solving fraction-based riddles. The immersive storytelling and competitive structure encouraged collaboration and sustained focus.

Across all sessions, the teacher-researcher documented strong student engagement, collaborative behaviour, and active problem-solving. Group discussions at the end of each session supported reflective thinking and knowledge consolidation. These results support the idea that non-digital educational games can foster both conceptual understanding and essential soft skills in mathematics learning.

To assess the effectiveness and reception of the educational games, a series of questionnaires were administered to the students at various stages of the study. These included:

- An initial questionnaire (prior to game implementation),

- Post-game questionnaires for *Maths Twins* and *Turtles, Seahorses and Octopuses*,
- A final questionnaire following all game activities.

Each survey aimed to evaluate students' engagement, learning experiences, and suggestions for improvement, using multiple-choice questions, quantitative Likert scale items and open-ended questions.

5.1 Initial Questionnaire: Students' Familiarity and Preferences

Out of a total of 84 students, 42 responses were collected, representing a 50% response rate. The results revealed a unanimous appreciation for games among respondents — 100% indicated that they enjoy playing games, with no neutral or negative responses. While half of the students preferred digital games, a significant proportion (38%) reported enjoying board and card games, highlighting a strong openness to non-digital formats. Paper-and-pencil games (7%) and other types (5%) accounted for the remaining responses. When asked which board or card games they enjoyed most, students mentioned popular titles such as *Monopoly*, *Uno*, and *Chess*.

When asked whether they would like to play board or card games that address mathematical content, the majority of students (93%) responded positively. This strong interest suggests a high potential for integrating such games as pedagogical tools in mathematics education.

These findings suggest that while digital games are more familiar, educational board/card games are also appealing and have potential in the classroom setting.

5.2 Maths Twins Questionnaire

Following implementation, 30 students (38% of the total) responded to a questionnaire on the *Maths Twins* game.

When asked if they enjoyed playing the game the responses were unanimous: 100% of respondents replied "yes".

Students were also asked to rate their level of agreement with a series of statements about the game, using a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). The heatmap in Figure 4 summarizes the responses.

The game Maths Twins:	1	2	3	4	5
was fun	0	0	2	11	17
was very difficult	0	5	7	10	8
helped me enjoy Mathematics more	0	0	5	10	15
helped me better understand the content taught in class	0	0	4	10	16
only served to distract me for a few minutes, nothing more	18	6	5	1	0
had an appropriate duration	0	1	6	9	14
promoted good interaction among classmates	0	1	3	8	18
increased my motivation to learn Mathematics	0	0	3	12	15

Figure 4: Students' perceptions of the Maths Twins game.

The heatmap in Figure 4 shows a strong positive reception of the *Maths Twins* game. Most students agreed that the game was fun, promoted peer interaction, and enhanced both their understanding of the material and motivation to learn mathematics. While some found it challenging, the difficulty level was generally seen as appropriate. Importantly, the majority disagreed with the idea that the game was merely a distraction, confirming its educational value. Overall, the results support the effectiveness of *Maths Twins* as a motivating and engaging learning tool.

Students' qualitative responses highlighted that the game *Maths Twins* significantly enhanced their motivation to learn mathematics. They emphasised that the game helped them think faster, made learning more enjoyable, facilitated group work, made mathematical calculations more engaging, and boosted their self-esteem and confidence.

Among the comments written by the students in the open-ended question of the questionnaire, the following stand out as representative:

- "The game was great fun, so I think maths can be fun too.".
- "The game helped to increase my motivation, because the game asked me to do calculations and it increased my self-esteem".
- "It helped motivate me to learn Maths because it was a lot of fun and it helped me to socialise more with my classmates".
- "It has increased my motivation because I don't like maths VERY much, but I like games and so it has been a way of having fun and learning more".

Overall, these comments suggest that the game not only supported mathematical understanding but also transformed learning into a more positive and motivating experience.

5.3 Turtles, Seahorses and Octopuses Questionnaire

This survey was completed by 10 students, one per team, in one of the classes. When asked if they enjoyed playing the game all respondents replied "yes". As in the previous section, students were asked to rate their level of agreement with a series of statements about the game. The heatmap in Figure 5 summarizes the responses.

The game Turtles, Seahorses, and Octopuses:	1	2	3	4	5
was fun	0	0	2	6	2
was very difficult	1	3	6	0	0
helped me enjoy Mathematics more	0	0	3	4	3
helped me better understand the content taught in class	0	0	1	5	4
only served to distract me for a few minutes, nothing more	0	1	0	2	7
had an appropriate duration	0	0	1	6	3
promoted good interaction among classmates	0	1	1	4	4
increased my motivation to learn Mathematics	0	0	4	3	3

Figure 5: Students' perceptions of the Turtles, Seahorses and Octopuses game.

The heatmap in Figure 5 shows that students generally had a positive perception of the game *Turtles, Seahorses, and Octopuses*. Most agreed it was fun, helped them understand class content, and had an appropriate duration. Although fewer students strongly agreed compared to other games, responses still reflected that the game supported learning and motivation. The responses indicate that the game was not perceived as overly difficult, with most students rating the difficulty as moderate or low. Overall, the game was seen as enjoyable and educational, with potential for further development.

Students' qualitative responses indicate that the game *Turtles, Seahorses, and Octopuses* contributed positively to their motivation to learn mathematics. They highlighted that it helped them better understand fractions and percentages, made learning more enjoyable, encouraged practical application of mathematical concepts, and increased their willingness to learn through games.

Among the comments written by the students in the open-ended question of the questionnaire, the following stand out as representative:

- "It helped me to understand fractions and percentages a little more."
- "It increased my motivation to learn maths because I could apply maths (percentages) to the game."
- "Playing makes me want to learn maths even more."

Overall, the game was seen as both educational and motivating, enhancing students' engagement with mathematical content.

5.4 Final Questionnaire

The final questionnaire was completed by 52 students (62% of the total).

As illustrated in Figure 6, the vast majority of students (96%) reported enjoying the games played during the lessons. When asked which game they preferred, students' responses were distributed across the three options (see Figure 7), with *Maths Twins* emerging as the most favoured, possibly due to its simple mechanics and immediate feedback. *Treasure Hunt on Maths Island* and *Turtles, Seahorses and Octopuses* were also well-

received, demonstrating that the variety of games successfully catered to different preferences and learning styles. This variety likely contributed to sustaining student interest and engagement across multiple sessions.

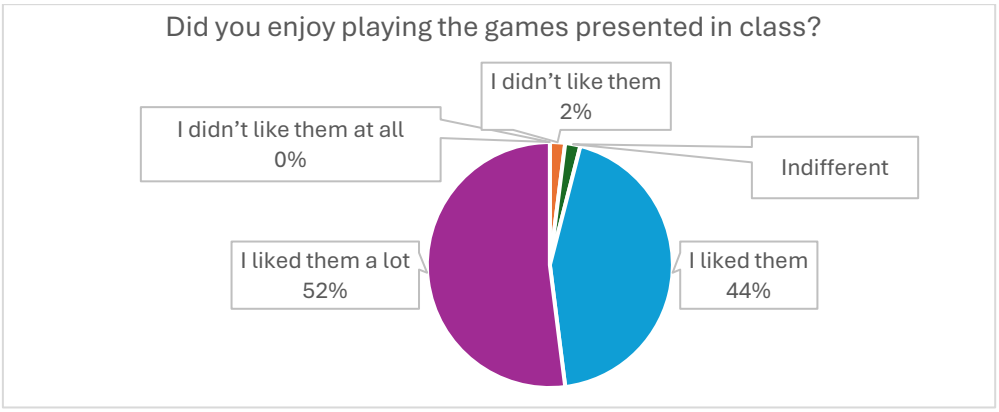


Figure 6: Students' enjoyment of the games

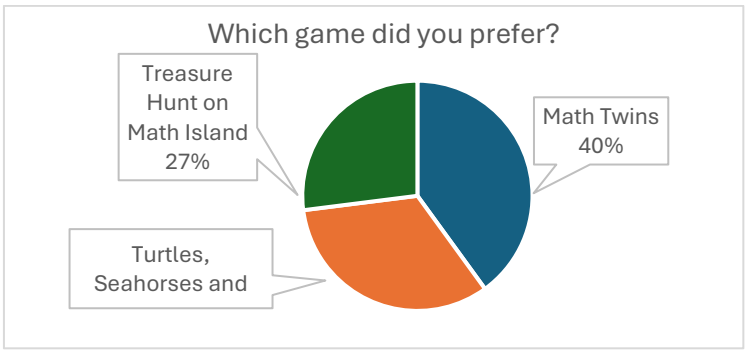


Figure 7: Students' preferences of the games

Figure 8 summarizes students' perceptions regarding the educational value of the games with 90% of students stating that they would like to continue playing games in the class. A large majority indicated that the games contributed to a better understanding of the mathematics content covered in class.

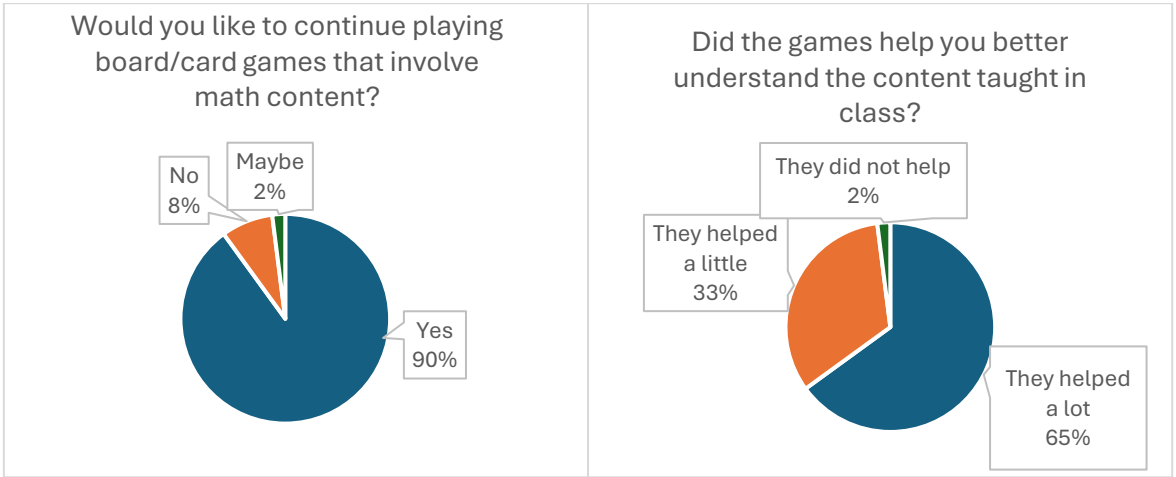


Figure 8: Perceived impact of the games in the class context and on learning

When asked whether the games increased their motivation to learn Mathematics, 90% of students responded "Yes," while only 10% answered "No." Similarly, 83% of students felt that the board/card games were useful for improving their relationship with classmates, whereas 17% did not perceive a benefit in this regard.

Across all questionnaires, student responses consistently emphasised that the games increased their motivation to learn mathematics, made learning more enjoyable and less stressful, encouraged teamwork and peer support, and helped consolidate and apply mathematical knowledge.

Although some improvements were suggested (e.g., more time and content variety), the overall reception was highly positive. These findings align with existing literature on game-based learning's impact on motivation, engagement, and collaborative skills.

6. Conclusions

This study aimed to explore the impact of non-digital board and card games as pedagogical tools for teaching rational numbers to Year 5 students. Drawing on the development and classroom implementation of three original games — *Maths Twins, Turtles, Seahorses, and Octopuses*, and *Treasure Hunt on Maths Island* — the research aimed to assess whether such physical games could enhance student motivation, engagement, and conceptual understanding in mathematics.

These games were purposefully designed not only to strengthen mathematical competencies but also to foster student engagement, teamwork, and confidence in handling abstract numerical concepts. Their adaptability and curricular alignment make them valuable resources for both formal lessons and reinforcement activities.

Findings from classroom observations and student questionnaires indicate that the use of these non-digital games fostered an interactive and collaborative learning environment. Students reported increased enjoyment and motivation to learn mathematics, which translated into improved participation and better grasp of mathematical concepts, particularly those involving rational numbers. The tactile and social dimensions of board and card games appeared to support knowledge retention while also reducing maths anxiety and encouraging active involvement.

In addition to academic gains, the games promoted the development of transversal skills such as teamwork, communication, and strategic thinking. These outcomes highlight the broader educational value of integrating playful learning approaches into traditional mathematics curricula.

By explicitly mapping the mechanics of each game to specific curricular goals, this paper contributes to the literature on game-based learning by offering a practical, replicable model for the integration of physical games in mathematics teaching.

Nevertheless, the study was subject to limitations, including a small sample size, a limited timeframe for game application, the absence of a control group, and its confinement to a specific educational context. These constraints suggest the need for further research to validate and expand upon the present findings.

Future work could explore the use of similar game-based strategies across different age groups, mathematical domains, or cultural contexts. Comparative studies between digital and non-digital game formats, as well as hybrid approaches, may also provide further insights into how best to make use of games in mathematics education.

In summary, this research reinforces the potential of non-digital educational games to transform the mathematics classroom into a more engaging, meaningful, and student-centred space. Their capacity to create inclusive, engaging, and conceptually rich learning environments makes them a viable alternative or complement to more traditional instructional approaches.

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Ethics declaration: The paper contains the result of a non-interventional study, i.e. a survey (qualitative questionnaires), which does not need ethical approval. The completion of the questionnaire was voluntary and anonymous; moreover school is the guarantor of data processing and privacy for activities performed in the curricular framework.

AI declaration: Use of generative AI in some paragraphs to improve the language, as English is not the authors' first language. Specifically used the question 'Check grammar and coherence without adding new sentences'. This prompt provides minimal suggestions for grammar, clarity and coherence in sentences, does not reorganise the sentences in the paragraph and does not add new sentences.

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