Fun and Functional: Using Non-Digital Games to Promote Maths Engagement in Pre-service Teachers

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Abstract: Humans naturally engage in playful activities throughout their lives and play serves as a fundamental mechanism for cognitive development as well as the development of essential soft skills such as teamwork, decision-making, leadership, and communication. Recognizing this innate predisposition for play, educators are increasingly embracing gamification strategies into their classrooms. More attention has been driven to digital tools such as platforms Kahoot! and Duolingo which gained popularity and demonstrated the potential of game-based learning to increase engagement and knowledge retention. However, concerns about digital screen time fuelled a renewed interest in non-digital activities, including educational games. Non-digital games are often more accessible and affordable, making them suitable for schools with limited resources. Research suggests that non-digital games can effectively promote collaboration, communication, and critical thinking skills. In addition, they offer flexibility to teachers to adapt rules and scenarios to specific learning objectives and student needs. Recognizing the benefits of employing games as a pedagogical strategy, the first author of this study opted to incorporate game-based learning strategies into her classes, on a regular basis. Throughout the semester, various non-digital games were implemented, inspired on well-known classics such as memory card games, Monopoly and Pictionary. These games were carefully designed to address specific mathematics topics identified as either the most relevant or those where students revealed more difficulties. The participants in this study were pre-service pre- and primary school teachers enrolled in a maths undergraduate course. Since these students are future educators, the games served a dual purpose: improving current learning experiences and providing teaching resources for their future classrooms. At the end of the semester, a survey was conducted to evaluate students' perceptions towards the use of games in the mathematics teaching-learning process. In this paper we describe some of the games used in this study and analyse the results of the survey. Previous studies reveal that students generally welcome the incorporation of games, perceiving them as effective tools for enhancing motivation and promoting positive learning outcomes. Our findings corroborate these studies.

Keywords: Educational Games, Gamification, Non-digital Games, Mathematics Education, Pre-service Teachers.

1. Introduction

Mathematics is present in almost everything that surrounds us. Although not everyone is always aware of it, it is a fact that the world we live in has always depended and will continue to depend, increasingly, on mathematics (Pais and Hall, 2019; Yadav, 2019). Unfortunately, the scenario in most mathematics classrooms in Portugal is not stimulating. The mathematics experienced by students is boring and monotonous (Alien-Fuller, Robinson, and Robinson, 2010; Grootenboer and Marshman, 2016). In an era of so many transformations, changes are also needed in the teaching and learning processes, namely, of mathematics. It is necessary to develop "powerful and challenging" mathematical tasks, "to captivate students and boost their learning" (ME, 2021).

Changes are needed in the teaching/learning processes, and it is necessary that the role of both teachers and students adapt to the demands of today's society. Active, cooperative, and participatory learning methodologies should be privileged, which promote, through interaction, voluntary, active, and conscious learning (Pais, 2023).

In this context, one of the strategies that has been used with good results is gamification, where games are not considered as a merely playful activity, but can be seen as resources that stimulate visual and intellectual contact with different contents (e.g. mathematics, language or history) and facilitate the learning process (Sailer and Homner, 2020; Dinata, 2021; Pais and Hall, 2021; Morando and Turconi, 2022).

2. Gamification

Gamification is an active educational methodology that uses elements, designs, mechanics and rewards from games or video games, adapted to a non-game environment such as the educational context (Kapp, 2012). This methodology provides a better experience in the learning process, promoting the interest of the students and involving them in this process, which has a positive impact on their results (Dinata, 2021; Morando and Turconi, 2022).

The learning mechanisms based on gamification are related to the student's motivation (Ryan and Deci, 2017), which is often associated with the factors of novelty, challenge, competition, fun and pleasure (González-Cutre et al, 2016). In this context, learning becomes enjoyable and not a duty or obligation. Several studies (McGonigal, 2011; Kapp, 2012; Hamari, Koivisto and Sarsa, 2014) highlight the positive impact of adopting gamification strategies in the teaching/learning process, both on student motivation and on the development of soft skills such as teamwork, creativity, decision making, leadership, communication, and critical thinking (some of the main skills mentioned by the World Economic Forum (2020)). Additionally, using gamification in education has other widely recognized advantages, such as: making learning more fun and interactive, creating an addiction to learning, stimulating brain connections, and allowing the establishment of relationships with the real world (Kapp, 2012; Pais and Hall, 2021).

Non-digital games, in particular, have additional benefits (Ramo, Knaul and Rocha, 2020), including: improving social relationships, promoting team spirit, cooperation, face-to-face interaction and communication with others, and providing a "relief" from the digital world and screens.

3. Educational Games for Mathematics Classes

Didactical games can be powerful tools in the classroom, transforming the classroom into a dynamic and engaging learning environment. To be effective, they need to be designed strategically. The following aspects should be considered when creating a game for mathematics classes:

- Alignment with the curriculum: Games should directly address topics and address student misconceptions identified through their mistakes. This clarifies doubts and focuses learning on challenging areas.
- Building automaticity: Games should include a myriad of exercises, thereby developing the essential automatisms crucial for mastering maths concepts.
- Active and enjoyable learning: By incorporating game elements, students actively engage with the content in a supportive and fun environment. This fosters a dynamic learning experience.
- Inclusive learning environment: Random elements like dice rolls or bonus points ensure everyone has the chance to succeed and contribute, regardless of skill level. This builds a collaborative and supportive classroom atmosphere where all students feel valued. It also adds excitement and teaches valuable life skills like adaptability and resilience.
- Simultaneous engagement: Effective games keep all students involved, even when it's not their turn. Non-playing teams can verify moves and answers, fostering collaboration and a sense of shared responsibility.
- Simple rules: Clear instructions ensure students understand the game mechanics quickly, allowing them to focus on the learning objectives. The game should be challenging enough to be interesting but not so difficult that it discourages participation.
- Adequate pacing: Maintaining the right pace keeps students engaged and motivated throughout the learning experience.
- Rewards and Penalties: Rewards, even small ones, incentivize active participation and a desire to excel. Penalties for random answers encourage students to approach the game seriously and strategically. A balance between rewards and penalties promotes both engagement and valuable lessons about focus and responsible decision-making.

The last two authors of this paper have a long experience in designing didactical games, targeting a wide range of educational levels (from primary school to university), in a diversified range of educational contexts (formal such as schools and prisons, and informal such as museums and botanical gardens) and, in some cases, taking into account students with special needs (La Fortuna, Morando and Spreafico, 2022; Morando and Turconi, 2022; Morando and Spreafico, 2023).

4. Methodology

4.1 Methodological Options

The research question underlying this study is how the incorporation of non-digital educational games in maths classes can enhance student motivation and engagement in learning mathematics.

In this perspective, a mixed case study was developed (quantitative and qualitative, based on a logic of complementarity), grounded on a pragmatic paradigm and case study design (Yin, 1994; Ponte, 2006). The teacher responsible for the course in question is simultaneously one of the researchers of this study.

In order to develop this experience, the techniques of inquiry, direct observation and analysis of documents were applied, and the following instruments were used: field notes and final questionnaire.

The main objective of the questionnaire was to assess students' perceptions regarding the use of educational games in the classroom. The questionnaire was created using Google forms and answered online by 44 students. This was a convenience sample, as participants were easily accessible to researchers. Statistical analysis of the data, specifically descriptive statistics, was performed using Excel.

4.2 Description of the Study

This case study was conducted during the first semester of the academic year 2023-2024 and involved the 1st year students enrolled in the course "Mathematical Concepts I" (Conceitos de Matemática I) of the undergraduate program "Basic Education" (Licenciatura em Educação Básica) at the University of Aveiro, Portugal. This three-year program prepares pre-service teachers for pre-school to the 6th year.

The course consists of two weekly face-to-face classes (one 2-hour sessions and one 3-hour session) and had a total of 28 sessions. Out of the 65 enrolled students divided into two groups, only 51 attended the classes (6 dropped out, and 8 only took the exams).

The topics of the course are numbers and operations. In the first part of the course different numeral systems are addressed and the students learn how to represent (and convert) numbers in different numeral systems and bases. The four basic operations are explored (addition, subtraction, multiplication, and division) and their algorithms are detailed not only in the decimal system but also in other bases. The second part of the course is devoted to elementary number theory: multiples/divisors, divisibility rules, prime number decomposition and applied problems are addressed. The third and last part of the course is related to decimal numbers (focusing on rational numbers), exploring the four operations both with fractions and/or decimal representations. Problem solving is also addressed using different approaches with a strong emphasis in the use of diagrams, following Singapore's bar model methodology.

Recognizing the benefits of games as a pedagogical strategy, the first author of this study integrated game-based learning strategies throughout the semester. Specifically, sixteen class sessions incorporated educational games. The activities were strategically placed in the middle of classes to serve as a mid-point break while still enhancing learning.

In total, eight different games were played, two of which were created in five different versions, addressing different mathematics contents. The time allocate to the games in class varied between 10 and 30 minutes, though most of the games were played for 15-20 minutes. All games were played in teams and most of them involved three to four teams, requiring several replicas to be played simultaneously. The games were designed to be diversified in many ways as shall be described in the next section.

5. The Games Played

All games applied in this study have been designed by the authors of this paper, in accordance with the principles described in Section 3. The authors chose to use only non-digital games for two key reasons. Firstly, the course itself is designed with a paper-and-pencil focus, aligning with the educational environment these pre-service teachers will likely encounter. Secondly, the instructors identified a need to address basic maths skills in many students and felt this could be best achieved without resorting to digital tools.

This section describes a selection of the most popular games, chosen in accordance with the students' preferences shown in the bar chart of Figure 6.

5.1 Garden Animals

The most preferred game was "Garden Animals" which focuses on developing mathematical communication skills and deals with simple operations and comparing quantities. It is intended for two teams of 2 to 4 players each.

Materials needed:

- One deck of 40 cards featuring images of garden animals (see Figure 1 (left) for some examples).
- One deck of 24 cards containing numeric conditions (e.g., "There are more snails and bees together than there are caterpillars").

Game Instructions:

- Display four cards from the image deck face-up on a table.
- Teams take turns drawing a card from the conditions deck.
- Each team has a limited time (one minute) to identify the image cards that satisfy the drawn condition.
- Correctly identified image cards are collected by the team.
- If the opposing team spots a wrongly collected card, it is returned to the table, and the playing team receives a penalty point.
- Once the team declares there are no more matching cards or the timer runs out, the empty spaces are filled with new image cards from the deck.
- The game ends when there are no more image cards left to display or after a predetermined time limit.
- The team with the most collected image cards wins.

5.2 Maths Monopoly

The second most preferred game was "Maths Monopoly" which draws inspiration from Monopoly. It can be adapted to different contents and in this case, we explored the properties of the arithmetic operations such as commutativity, associativity, and the existence of a unit element. It's designed for 2 to 4 teams, with 2 to 3 players per team.

Materials needed:

- "Title Deed" Cards (deck of 40): These cards feature numerical sets coupled with arithmetic operations (e.g., "The set of even numbers with addition").
- Board Cards (deck of 24): one "Start" card, five cards saying "Chance"; four cards saying "Closure"; seven cards saying "Commutativity and Associativity"; seven cards saying "Other properties".
- Chance Cards (deck of 12): These contain random bonuses (e.g., "Draw two cards of your choice").
- "Money" Cards (three decks):
    - Closure Cards (deck of 24): These represent closure properties (e.g., "The set is closed for the operation").
    - Commutativity and Associativity Cards (deck of 48): These represent properties (e.g., "The operation is associative").
    - Other Properties Cards (deck of 48): These represent other mathematical properties (e.g., "The operation has a unit element, and it is in the set").
- Dice (two) and tokens (one per team).

Game Instructions:

- Place six "title deed" cards face-up in a rectangular grid (2 rows x 3 columns).
- Shuffle the board cards and randomly arrange them face-up around the rectangle, placing the "Start" card in a corner (Figure 1 (right)).
- Place all team tokens on the "Start" card.
- In turns, teams draw the dice and move their token the corresponding number of spaces around the board. Depending on the landed card, a card is drawn from the respective deck. Chance cards must be placed back in the deck. The other cards are kept.
- A "title deed" may be bought if a team is playing on its turn and has gathered three "money" cards that match the title. One of the cards must be a closure card. For instance, a team can buy (collect) "The set of integer even numbers with addition" handing in the cards "The set is closed for the operation" "The operation is commutative" and "The operation has a unit element, and it is in the set".

- The game ends after a predetermined time and the team with more title deeds wins.

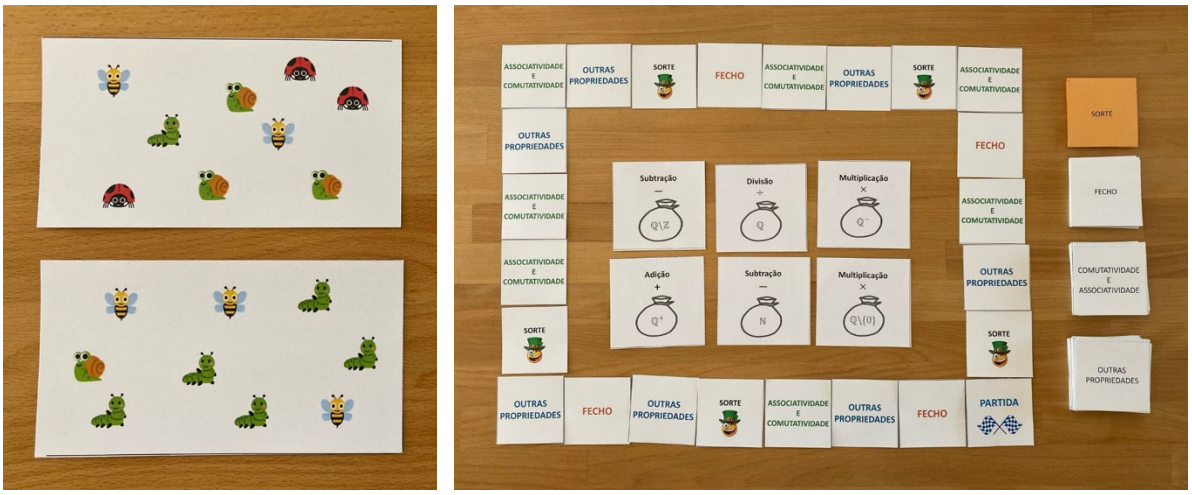

Figure 1**: Photos of "Garden Animals" (left) and "Maths Monopoly" (right).**

5.3 Mysterious Divisor

The third most liked game was "Mysterious Divisor" which explores prime factor decompositions and divisibility. It is designed for two teams of 2 to 4 players each.

Materials needed:

- Two identical decks of 20 cards featuring numbers and their prime factor decomposition (e.g., $1144=2^3$x11x13).
- One deck of 20 cards containing numeric conditions (e.g., "N is multiple of 26")

Game Instructions:

- Each team receives one of the identical decks and spreads it face-up on the table.
- Afterwards, each team draws one card from the conditions deck and reorganizes its deck by placing all number cards that satisfy the condition on the left-hand side of the table and all other number cards on the right-hand side. All cards must remain visible.
- Once ready, each team observes the other team's cards and tries to guess the drawn condition.
- Teams earn one point for correctly identifying the opposing team's condition.
- The game ends when there are no more condition cards left to draw and the winning team is the one with most points.

5.4 Boxes Game

This game is a fun activity that gets teams moving around the classroom! It's designed for the whole class, divided into four competing teams.

Materials needed:

- Five boxes placed around the room. Each box should be labelled with a different number range.
- Four decks of 20 cards. Each deck should be a different colour, but all decks should have the same contents. Each card must represent a number (it can be a numerical expression, a numeral in a certain numeral system, an equation with a single solution, etc.)

Game instructions:

- Divide the class into 4 teams.
- Each team chooses one member to be the messenger. He is responsible for placing the cards in the correct boxes.
- The remaining members must look at the cards and find the destination boxes.

- Teams have five minutes (or another pre-fixed time limit) to place the largest number of cards in the correct boxes. The time limit should be tight enough that players can't place all the cards. This encourages strategic thinking about which cards to analyse first.
- At the end of the game, each box is checked for correct and incorrect cards:
    - Each correct card earns the team 1 point.
    - Each incorrect card costs the team 1 point.
    - The team with the most points at the end of the game wins.

In this game the cards had numbers written in different bases and numeral systems (Roman, Egyptian, and Babylonian).

5.5 Decimal Numbers Pictionary

"Decimal Numbers Pictionary" takes inspiration from the classic game Pictionary and is designed for teams of 3 to 4 players.

Materials needed:

- Several identical decks of cards containing rational numbers in decimal form (terminating decimals).

Game Instructions:

- Distribute one deck of cards to each team.
- Each team chooses a member as the guesser (which can change every time a new card is drawn).
- The remaining team members draw a card from the deck and read the number on the card aloud, in its full form.
- The guesser writes the number down back in decimal form (e.g., the card has the number 23.5096; the readers say "twenty-three units, five thousand and ninety-six ten thousandths"; the guesser writes 23.5096).
- Each correct guess earns the team one point.
- The game ends after a predetermined time and the team with most points wins.

5.6 Open Middle

This game draws inspiration from the open middle maths problems available at https://www.openmiddle.com/. The proposed challenges all require selecting digits to place in blank spaces, without repeating any (e.g., Maximize $\square\square + \square\square$, using the digits 1 to 9 without repeating). It is designed for 2 to 4 teams of 2 players each.

Materials needed:

- A deck of chance cards with five types of cards: "all teams play" (most common card); "only your team plays"; "only the other teams play"; "earn one point"; "lose one point".
- A deck of challenge cards with solutions on the back.
- A timer.
- Paper and pencils for each team/player.
- Beans (points).

Game instructions:

- Each team takes turns drawing a card from the deck of chance cards.
- If the drawn card indicates a game for one or all teams, the team draws a card from the deck of challenge cards.
- Set a timer for one minute (or the time limit stated on the card).
- All teams try to solve the challenge using paper and pencil, if necessary.
- At the end of the timer, the teams flip over the challenge card to reveal the correct answer.
- Each team that correctly solved the challenge earns one point.
- After a pre-establish game time, the team with the most points wins.

The game was played in five class sessions and the topics covered were addition and subtraction of integers, hours and minutes, divisibility rules, mixed numbers, and fractions.

6. Survey Results

At the end of the semester, students completed a four-part questionnaire. The first section focused on participant characterization, the second section addressed the use of games in class, the third section (not analysed here) covered assessment methods, and the final section dealt with general course evaluation.

Regarding participant characterization, student ages ranged from 17 to 54 years old. The majority (81.8%) were between 17 and 19 years old, with only eight students (18.2%) aged 20 or older. Most students were full-time students (86.4%), while the remaining 13.6% were working students. The gender breakdown was heavily skewed towards females (95.5%), with only two male students (4.5%). This is usual in the "Basic Education" degree.

The second section of the questionnaire first asked students if they liked playing educational games in the classes, through a five-point Likert scale. As Figure 2 shows, there were no negative responses.

Figure 2: Pie chart of responses for the first question of the second section.

Further on, students answered four questions concerning educational games in maths classes. The responses are summarized in Figures 3 and 4.

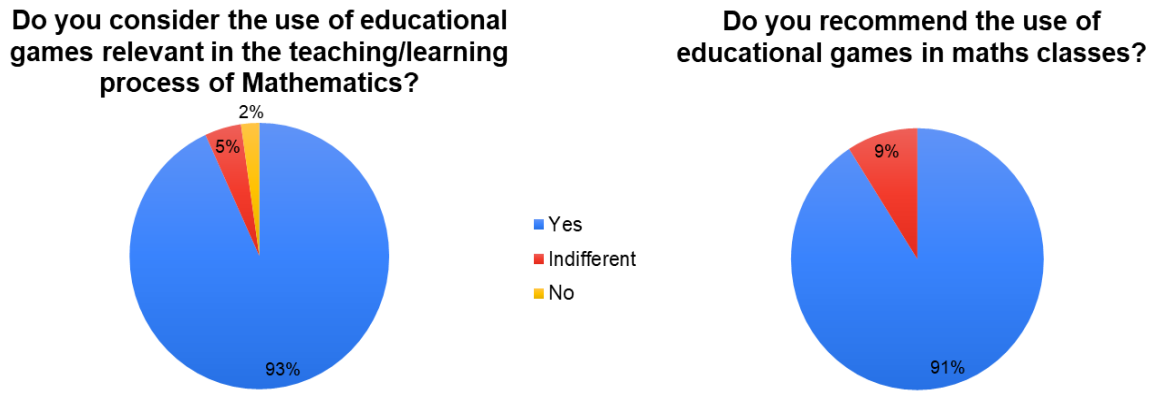

Figure 3: Pie chart of responses (Questions 2 and 3).

Figure 3 indicates strong student agreement that games are a valuable resource in the teaching/learning process. Additionally, students recommend using educational games in maths classes.

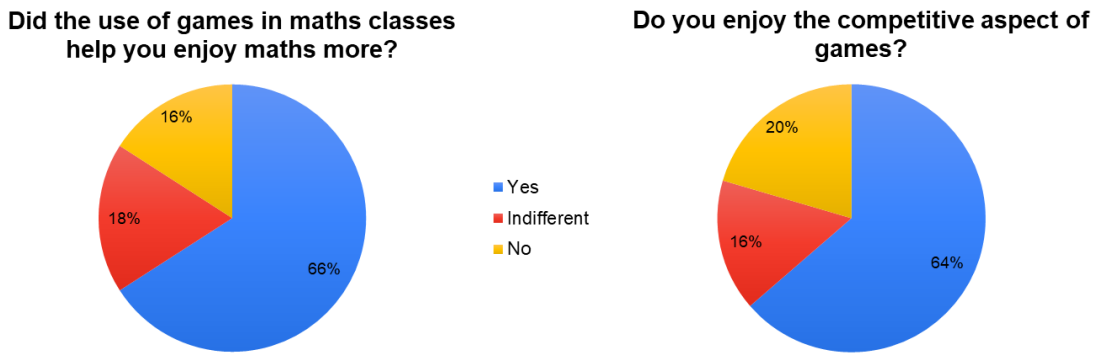

Figure 4: Pie chart of responses (Questions 4 and 5).

Figure 4 (left) shows that most students (66%) enjoyed maths more due to the use of educational games in class. However, the competitive aspect of gamification has varying appeal. While 20% of students reported disliking it, another 16% remained neutral.

Students rated their agreement with a set of statements concerning the use of educational games in class using a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). The results are presented in the heatmap of Figure 5, which also includes the mean and standard deviation (SD) of the responses.

The use of educational games in maths classes contributed to:	**1**	**2**	**3**	**4**	**5**	**Mean**	**SD**
making learning more interesting.	0	1	4	14	24	4,4	0,8
making learning more interactive.	0	0	4	9	30	4,6	0,7
making classes more stimulating.	0	0	6	13	24	4,4	0,7
involving the students in the learning process.	0	1	2	15	25	4,5	0,7
increasing student motivation.	0	3	5	14	21	4,2	0,9
a more positive view of mathematics	0	0	8	17	18	4,2	0,8

Figure 5: Heatmap of responses related to the use of games in maths classes.

As Figure 5 shows, very few respondents disagreed with any of the statements. "Total agreement" was the most frequent response for all statements, reflected in a mean agreement level above 4 and a small SD. The heatmap allows us to conclude that the use of educational games generally contributed to motivating students, making the learning process more interactive, and engaging students in the teaching/learning process.

Students were asked to select which games they liked better (they could choose more than one). The answers are given through the bar chart of Figure 6.

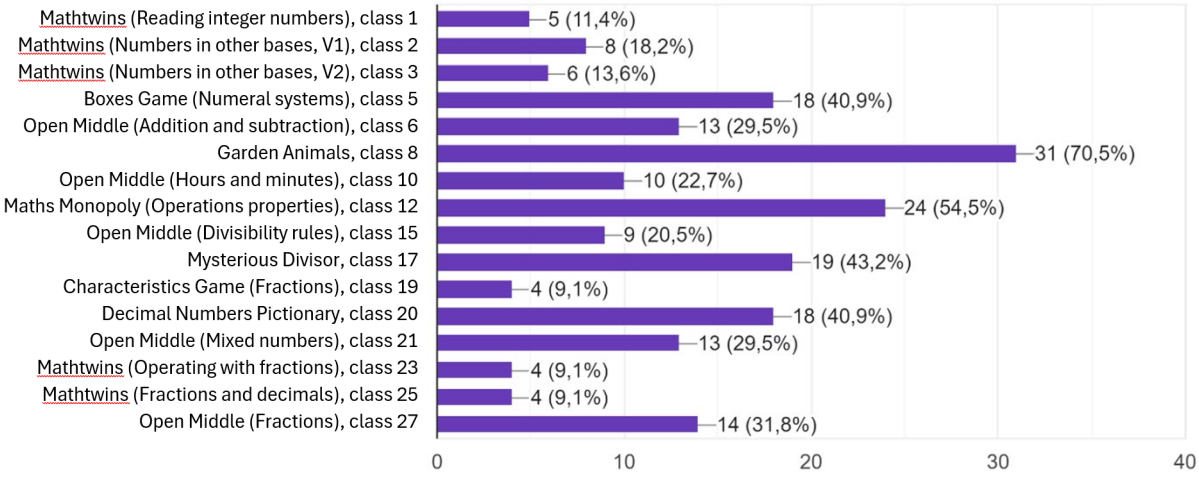

Figure 6: Bar chart of preferred games.

To gain a deeper understanding of student perceptions regarding the competitive aspect of games, they were asked to rate their agreement with a set of statements on a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). The results are presented in the heatmap of Figure 7.

I consider that the pressure of competition contributes to increasing:	**1**	**2**	**3**	**4**	**5**	**Mean**	**SD**
my responsiveness.	3	4	8	18	11	3,7	1,2
my motivation to succeed.	3	5	7	15	14	3,7	1,2
the fun with the activity.	3	4	7	12	18	3,9	1,2

Figure 7: Heatmap of responses related to the competitive aspect of games.

Analysing the results of Figure 7, we see less consensus in opinions, reflected in an increase of the SD and a decrease of the mean responses. This aligns with the findings from Figure 4 (right-hand pie chart), where 36% of the students didn't have a positive opinion. Not everyone thrives in competitive environments, and although a minority in this group, they should not be neglected. One solution involves grouping these students together and facilitating non-competitive gameplay. The teacher successfully employed this strategy to accommodate students' diverse preferences.

In the final section of the questionnaire, students were asked to assume the role of the teacher and outline what they would maintain and modify for next year's course. Regarding what they would maintain, seven students said they would keep everything as-is. Educational games received the strongest attention, with another 26 students advocating for their continued use. Two students did not respond, while the remaining suggestions focused on other resources and methodologies employed in the course.

When asked about potential modifications, 17 students felt nothing needed to be changed. The remaining students suggested adjustments to the pace of content delivery or the need for breaks during class. No modifications related to gamification were proposed. It's important to note that the games were played mid-class, and complete breaks were not permitted. The teacher agrees with the students who highlighted the need for breaks, particularly during the 3-hour sessions.

7. Conclusions

This study investigated how educational non-digital games in maths classes can contribute to increase student motivation and engagement in maths learning. The results demonstrated that students not only enjoyed playing the games, but also reported feeling more involved in class and motivated to learn. These findings were supported by both questionnaire responses and the teacher's field notes taken during class observations.

Games offer both a leisure aspect and a competitive element. While most people enjoy the leisure side, not everyone embraces the competitive nature of games. In this study, none of the students reported disliking the educational games played throughout the course. However, 20% did indicate a preference for playing without competition. To accommodate these varying preferences, we recommend adapting the game rules for different student groups. For most students, a point and penalty system can provide a welcome challenge. However, others may benefit from a more collaborative setup that removes the competitive aspect. Ultimately, the teacher's role is to tailor the game format to best suit the players.

Students in this study not only found educational games to be a valuable tool for the teaching/learning process, but also recommended their use in classrooms. The participants, pre-service teachers enrolled in a mathematics undergraduate course, not only strengthened their own understanding of mathematical concepts through these games, but also gained valuable teaching resources for their future classrooms.

In summary, using non-digital educational games to promote maths engagement in pre-service teachers was found to be both fun and functional.

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