Beyond Traditional Teaching: Games and Origami as Tools for Mathematics Learning

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Abstract: The use of innovative and engaging teaching methodologies is crucial in the education of future teachers, as it improves their current learning experiences and provides valuable teaching resources for their future classrooms. This paper presents a study which explores the integration of games and origami as educational tools in a math course for pre-service teachers. The implementation of playful challenges in mathematics education encourages students to apply mathematical concepts in a practical and interactive manner, thereby enhancing their engagement and comprehension. Furthermore, these strategies extend beyond reinforcing curricular content. They help foster a more positive attitude towards the subject matter. The activities were carefully designed to address specific mathematics topics identified as either the most relevant or those where students revealed more difficulties. At the end of the semester, a survey was conducted to evaluate students' perceptions towards the use of games and origami in the mathematics teaching-learning process. In this paper we describe some of the activities designed for this study and analyse the results of the survey. Previous studies reveal that students generally welcome the incorporation of games and origami, perceiving them as effective tools for enhancing motivation and promoting positive learning outcomes. Our findings corroborate these studies.

Keywords: Educational non-digital games, Game based learning, Mathematics education, Origami, Pedagogical innovation

1. Introduction

Mathematics is present in almost every aspect of our every-day life. Although not everyone is constantly aware of it, the reality is that the world we inhabit has always relied on mathematics and will continue to do so with increasing significance (Pais and Hall, 2021; Yadav, 2019). Unfortunately, the learning environment in most mathematics classrooms in Portugal is not particularly stimulating. The mathematics experienced by students is often perceived as painful and monotonous (Alien-Fuller, Robinson, and Robinson, 2010; Grootenboer and Marshman, 2016). In an era of rapid transformation, changes are also required in the teaching and learning processes, particularly in mathematics. It is essential to develop "powerful and challenging" mathematical tasks "to captivate students and enhance their learning" (ME, 2021).

In recent years, there has been a growing interest in innovative teaching and learning methodologies, particularly those that foster engagement and motivation among students. In this context, gamification and origami have emerged as powerful pedagogical strategies, leveraging game elements to create dynamic and interactive learning environments (Goland and Jackson, 2009; Kapp, 2012; Morando and Turconi, 2022; Pais and Hall, 2024).

Gamification involves the application of game mechanics, such as points, badges, leaderboards, and challenges, to non-game contexts (Kapp, 2012), with the aim of increasing motivation and engagement (Morando and Turconi, 2022; Pais and Hall, 2024, Ryan and Deci, 2017). The underlying principle is that by integrating elements typically found in games, learners can experience a sense of accomplishment, competition, and enjoyment, which, in turn, enhances their learning process (Hall et al, 2024; González-Cutre et al, 2016). This approach has been widely adopted in various educational settings, demonstrating its potential to improve students' participation, knowledge retention, and overall learning experience.

2. Gamification

Gamification has emerged as a promising pedagogical strategy to increase learner motivation and engagement by integrating game design elements into educational settings. Unlike traditional instruction, gamified experiences often leverage mechanisms such as point systems, badges, leaderboards, challenges, and narrative contexts to sustain students' interest and foster active participation (Dinata, 2021; Kapp, 2012; Hamari, Koivisto and Sarsa, 2014). These elements can promote both intrinsic and extrinsic motivation, supporting goal-setting, and feedback loops.

Research shows that the effectiveness of gamification depends not only on the mechanics used but also on how well these are aligned with learning objectives, the learners' characteristics, and the broader learning context (Seaborn & Fels, 2015; Toda et al., 2019). For example, meaningful gamification, where game elements are intentionally connected to pedagogical outcomes, has been found to yield more sustainable engagement and deeper learning (Landers, 2014).

The effectiveness of gamification is influenced by various factors, including the design of the gamified experience, the context in which it is implemented, and the individual preferences of learners. Several studies highlight the positive impact of gamification on motivation and learning outcomes (McGonigal, 2011; Kapp, 2012; Hamari, Koivisto and Sarsa, 2014). However, as pointed out by Hall et al. (2024), the success of gamified activities relies on thoughtful instructional design that integrates game-based principles without compromising mathematical rigour.

3. Educational Games and Origami Activities for Mathematics Classes

Educational games can transform the mathematics classroom into an environment where students learn through exploration, experimentation, and play. When designed with pedagogical intention, these games contribute to the development of mathematical fluency, procedural understanding, and conceptual insight (Perrotta et al., 2013; Plass, Homer and Kinzer, 2015). Essential design principles for effective mathematics games include (Kapp, 2012; Hall et al, 2024):

- *Curriculum Alignment*: Games should target curricular goals and address common misconceptions.
- *Skill Development*: Varied exercises build fluency and reinforce math skills.
- *Engagement*: Game elements make learning interactive and fun.
- *Inclusivity*: Random elements allow all students to participate, promoting collaboration and resilience.
- *Full Participation*: All students stay involved, even when not actively playing.
- *Clear and Challenging*: Simple rules and balanced difficulty keep students interested.
- *Good Pacing*: Steady pacing maintains motivation.
- *Smart Incentives*: Small rewards and gentle penalties encourage strategic thinking.

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; Hall et al., 2024)

In parallel, origami-based activities offer a tactile and visual approach to mathematics education. Beyond their aesthetic appeal, they facilitate deep conceptual understanding by linking abstract mathematical ideas to concrete, hands-on experiences (Golan and Jackson, 2009; Hull, 2013; Wares and Valori, 2020). They can be designed to address a wide range of topics throughout the folding process—not only in geometry but also in areas such as arithmetic and fractions (Frigerio and Spreafico, 2018). Furthermore, the use of origami in an educational context "enhance self-esteem and a sense of accomplishment, while developing learning skills such as motor skills, spatial perception, logical and sequential thinking, hand-eye coordination, focusing and concentration, aesthetics, 3D perception, and principles of basic geometry" (Goland and Jackson, 2009, p. 1). Other studies reach similar conclusions, also referring an increase in the perseverance in problem-solving tasks (Higginson and Colgan, 2001; Cipoletti and Wilson, 2004; Tubis and Mills, 2006).

The fourth author of this paper has developed several origami-based activities covering diverse mathematical topics and educational levels. For example, Spreafico (2023) presents an origami activity for practising multiplication, while Magrone, Morando and Spreafico (2025) propose an activity addressing the concept of domain of a function and its behaviour at the boundary of the domain alongside two optimisation problems, emphasising real-world applications and creative problem-solving.

4. Methodology

4.1 Methodological Options

The research question underlying this study is how the incorporation of non-digital educational games and origami activities 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 and origami in the classroom. The questionnaire was created using Google forms and answered online by 27 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 2024-2025 and involved the 1st year students enrolled in the course "Complementary Mathematics I" (Matemática Complementar I) of the masters' program "Master in Teacher Education - Pre-school education and 1st cycle of basic schooling" (Mestrado em Educação Pré-Escolar e Ensino no 1º Ciclo do Ensino Básico) at the University of Aveiro, Portugal. This two-year program prepares pre-service teachers for pre- and primary school levels.

The course consisted of a weekly three-hour face-to-face class, totalling 14 sessions. Of the 45 students enrolled, 41 attended the classes (one dropped out, and three only took the exams).

The course focused on two main topics: geometry and problem solving. The first part of the course explored geometry problems involving perimeter, area, and volume, beginning with a review of fundamental concepts such as segments, lines, and angles. The second part of the course addressed geometric transformations, with a strong emphasis on plane isometries. This was followed by an exploration of planar symmetry, concentrating on the symmetry groups of rosettes, friezes, and wallpaper patterns, using classification flowcharts by Washburn and Crowe (1988) . The final part of the course was dedicated to problem solving through various approaches, with particular emphasis on the use of diagrams, following the bar model methodology from Singapore mathematics (Forsten, 2010).

Recognizing the benefits of game-based learning and other hands-on activities as pedagogical strategies, the first author of this study integrated non-digital games and origami activities throughout the semester. Students engaged in four games and completed three origami activities.

5. The Games Played

All the games 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 (pre-school and primary school levels). Secondly, the teacher 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 the four games played.

5.1 Euclid's Regatta

Euclid's Regatta is an educational game designed to help students understand and apply concepts from plane geometry and point location through playful, hands-on interaction. The game is intended for two teams of 3–4 players each and involves physical materials including:

- A small origami boat for each team
- Cotton thread to represent lines or segments
- Buttons to represent points
- Adhesive (Patafix) for fixing elements on the game board (table)
- A timer to track performance

- A table for registration of times per team/challenge.

The game is structured into five challenges, each set up on table and involving a specific geometric task. Teams take turns trying to position their boat according to the challenge instructions.

Gameplay Mechanics

All boats start from the same position on the table. To decide who begins the first challenge, both teams roll dice – the highest result starts. In subsequent rounds, the losing team begins. If there is a tie, dice are rolled again. During a turn, a player must blow on the boat to guide it into the correct position – touching it by hand is not allowed. The timer starts at the beginning of the attempt. If the boat falls off the table, 30 seconds are added and the boat restarts from its original position. Once the team believes the boat is correctly positioned, they call out, and the opposing team stops the timer and verifies the placement. Incorrect placement results in a 30-second penalty. The team then registers the time needed to complete the task.

The second team then takes their turn following the same procedure. After completing the five tasks, The team with the shortest cumulative time wins.

The types of challenges in this game can be quite varied. For example, one challenge in this version required positioning the boat on the line perpendicular to line r (represented by a piece of string) and passing through point P (represented by a button), as illustrated in Figure 1 (left).

5.2 Isometries in the Square

"Isometries in the Square" is an educational board game designed to help students explore and apply concepts related to plane isometries, specifically translations, reflections, and 180º rotations. The game is intended for three teams of 2–3 players each and promotes spatial reasoning, mathematical thinking, and teamwork through playful interaction.

Game Components

- A 10x10 square grid game board with three coloured lines all meeting at the central point. Two of the lines represent the coordinate axis and the third one is the bisector of the first and third quadrants quadrant.
- A deck of 60 action cards
- 120 coloured buttons (40 of each of three colours)

Gameplay description

- Each team receives 40 buttons of a specific colour and places three buttons of their choice anywhere on the grid as an initial configuration. The action card deck is shuffled and placed face down.
- The aim of the game is for teams to place the largest number of connected (adjacent by side or vertex) buttons of their colour on the board by performing geometric transformations indicated by the action cards.
- Teams take turns drawing one action card from the deck. Depending on the card drawn, teams must place new buttons on the board by performing a specified isometry (translation, reflection, or rotation) using one (or two) of their existing buttons as a reference point.
- If the card has no special symbol, the team places one button. For example: A card stating “Reflection across the green line” allows a team to place a button in the square that is symmetric (by reflection) to one of their own buttons across the green line.
- If the card displays a double-heart symbol, the team must use a pair of adjacent buttons (sharing an edge or vertex) and place two new buttons, each following the transformation specified.

Rules

- Buttons may not be placed in occupied squares.
- For double-hearted cards two adjacent squares must be used.
- If there are no empty squares satisfying the card condition the player must pass his turn.

The game ends when the action deck is exhausted.

At the end of the game, teams score one point for each button that is adjacent (by side or vertex) to at least one other button of the same colour. The team with the highest score wins. Figure 1 (right) shows the board of one of the playing groups close to the end of the game.

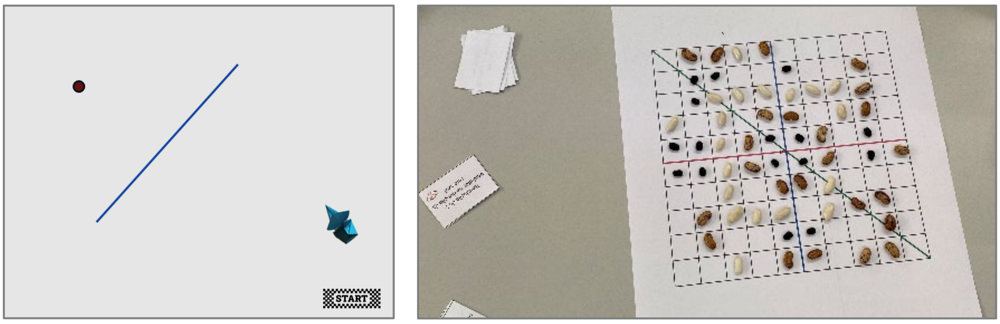

Figure 1: Illustration of "Euclids' Regatta" (left) and photo of "Isometries in the Square" (right).

5.3 Symmetry in Action

"Symmetry in Action" is an educational game for two teams of two students each, designed to promote geometric reasoning and spatial awareness by challenging students to construct figures that exhibit specific symmetrical properties.

Unlike traditional exercises that require identifying symmetries in pre-drawn shapes, this game reverses the process: students are asked to create figures that satisfy given symmetry conditions. This inversion enhances understanding by actively engaging learners in the construction of symmetry. However, it increases the level of difficulty of the game.

Game Components

- Two decks of 12 identical tiles. (the decks are different from each other but with similar symmetry characteristics; we used two tiles designed by the Portuguese artist Eduardo Nery (1938-2013) shown in Figure 3)
- A deck of 36 condition cards specifying symmetry requirements (for rosettes and friezes)

Game objective and instructions

- The objective is for teams to construct geometric figures that fulfill the symmetry conditions specified on the cards, using their set of tiles.
- Each round begins with the teacher drawing a card from the condition deck and reading it aloud (alternatively, teams may take turns drawing and reading cards themselves). Each card presents a specific condition—for example, "build a 2x2 square rosette with only rotational symmetry of order 2 (C_2)," or "build a frieze with a 2x2 unit cell featuring only translational symmetry (p111)"
- Teams then use their tiles to construct a figure that satisfies the condition described on the card.
- Once a team believes their configuration meets the requirement, they declare it.
- If the proposed figure is correct, the team earns one point.
- If it is incorrect, they receive one penalty point, and the other team may attempt the challenge. If the second team's figure is correct, they earn one point.
- After points are awarded, a new card is drawn, and the next round begins. The game continues for a fixed number of rounds or within a predetermined time limit.
- The team with the highest number of points at the end of the game is declared the winner.

Figure 3 shows the tiles used in this game and two examples of challenge solutions: "build a 2x2 square rosette with exactly two axis of symmetry (D_2)" (left); "Build a 2x2 square rosette with rotational symmetry of order 4 and no reflection symmetry (C_4)" (right) .

Figure 2: Symmetry in Action: The two tiles by Eduardo Nery and examples of challenge solutions

5.4 Problem Basket

This game is a treasure hunt-style game that challenges teams to solve a series of problems. The solutions to these problems lead to the discovery of a magic word. The game aims to develop problem-solving skills.

The game was played within the topic of problem solving and addressed different mathematical topics. Several problems involved doing measurements in the classroom or the building. The game can be adapted to any mathematical context and it is described in Pais and Hall (2024).

6. The Origami Activities

In this section we describe the three origami activities performed during the semester.

6.1 Euclid's Boat

Euclid's Boat is an origami model required for playing Euclid's Regatta. While folding the boat, students follow step-by-step instructions designed to explore fundamental geometric concepts through hands-on practice. Along the way, they are prompted to analyse each step from a mathematical perspective, identifying the geometric construction involved and the corresponding Huzita–Hatori axiom applied.

This system of axioms formalises the geometry of paper folding and includes operations such as folding a line through two given points (Axiom 1), creating the perpendicular bisector of a segment by folding one point onto another (Axiom 2), and constructing the angle bisector formed by two intersecting lines (Axiom 3). The folds involved in constructing the boat encompass all three axioms. Figure 3 (left) shows the resulting origami boat.

6.2 Greenhouses

This activity has been proposed by Morando and Spreafico (2023) within the context of an outreach mathematical activity in a botanical garden. In this activity, students are challenged to build paper greenhouses using a simple origami model that results in a pentagonal prism shape (see Figure 3, centre, for the resulting models). As they progress, they are encouraged to analyse the 2D and 3D geometric forms involved, culminating in exercises focused on calculating perimeter, area, lateral surface, and volume based on the cross-sections of the models.

To deepen understanding, students compare different greenhouse configurations by modifying roof angles and base dimensions. These variations lead to meaningful discussions on how structural changes affect geometric properties, supported by calculations and percentage comparisons. An extension of the activity introduces the concept of scale, prompting students to determine whether a full-size greenhouse, proportionally scaled from the origami model (e.g., 1:90), could accommodate a 5-meter-tall tree.

Through these tasks, the activity integrates geometry, real-world problem solving, and proportional reasoning, while also allowing for creativity through optional model decoration.

6.3 The Fraction Fish

The third origami activity, known as The Fraction Fish, is designed to support the exploration of fractions through a progressive paper-folding process. This activity has been proposed by Frigerio and Spreafico (2018, pp. 153–160) as a way to integrate mathematical reasoning into hands-on learning. Using a square sheet of paper (15×15 cm), students follow guided folding steps to create a stylised fish, pausing at key stages to analyse and quantify the relationship between the coloured and white regions of the model.

At each stage, students are prompted to identify a suitable unit of measure—such as a rectangle, square, or triangle—and to express the parts of the model as fractions of the whole. This approach enables discussions on a range of fractional concepts, including complementary fractions (e.g., 1/3 + 2/3 = 1) and equivalent fractions (e.g., 1/3 = 4/12 or 2/30 = 1/15). By changing the reference unit throughout the activity, students develop a flexible understanding of how fractional values can vary depending on the unit chosen.

As the model evolves, increasingly complex comparisons are introduced, involving fractions with denominators such as 8, 14, and 30. The activity concludes with the completed fish model (see Figure 3, right), after engaging students in repeated reasoning with fractional decomposition, equivalence, and unit-based comparisons, all within a visual and hands-on learning experience.

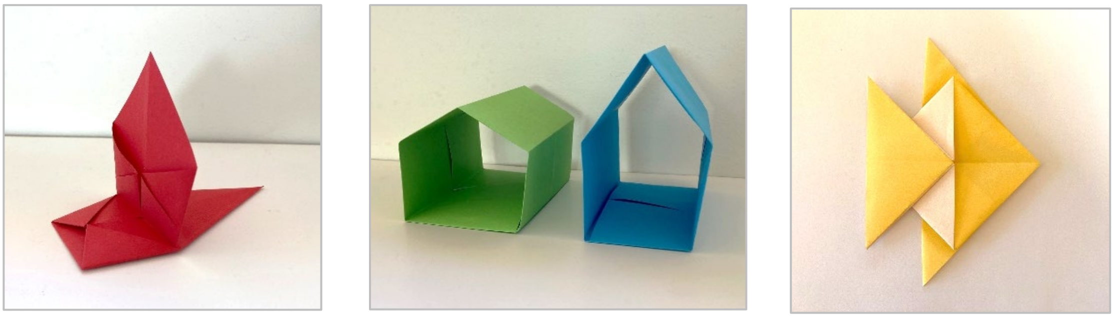

Figure 3: Photos of the origami models: Euclid's Boat (left), Greenhouses (centre) and Fraction Fish (right)

7. Survey Results

At the end of the semester, students completed a five-part questionnaire. The first section focused on participant demographics, the second on the use of games in class, and the third on the use of origami. The fourth and fifth sections (not analysed here) concerned assessment methods and general course evaluation.

Regarding participant characterization, student ages ranged from 19 to 33 years old. The majority (70%) were between 19 and 22 years of age, with only one student (4%) over 26. Most were full-time students (96%), and only one (4%) reported working while studying. The gender distribution was highly skewed toward female students (85%), which aligns with trends in pre-service education programs for pre- and primary school teaching.

7.1 Use of Games in Class

Students were first asked to express their overall appreciation for playing educational games in class using a five-point Likert scale (1 – disliked very much; 5 – liked very much). As shown in Figure 4, all responses were positive, with no students selecting neutral or negative options.

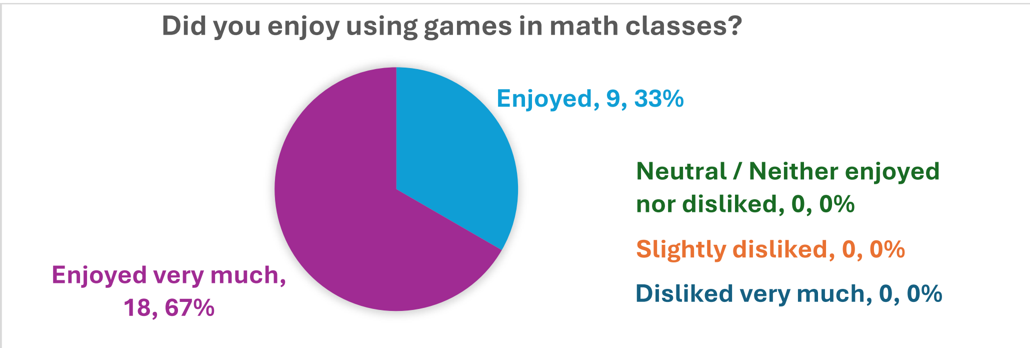

Figure 4: Pie chart of responses for the question "Did you enjoy playing educational games in class?"

Next, students were asked whether they considered the use of games to be relevant in the teaching and learning of Mathematics. All respondents answered "Yes," indicating a unanimous perception of games as valuable pedagogical tools. When asked if they would recommend using games in math classes, 93% of students responded affirmatively, while one student (4%) selected "Indifferent"; no one answered "No."

Students were also asked to rate their level of agreement with a series of statements about the impact of educational games in the classroom, using a five-point Likert scale (1 = Strongly Disagree; 5 = Strongly Agree). The heatmap in Figure 5 summarizes the responses, including mean and standard deviation (SD).

The results indicate a clear consensus on the positive impact of games in class. The highest frequency of responses was "5 – Strongly Agree" for all statements, with mean values above 4 and relatively low standard deviations. These findings suggest that the use of educational games contributed to making learning more interactive, stimulating, and motivating for students.

The use of educational games in maths classes contributed to:	1	2	3	4	5	Mean	SD
making learning more interactive.	0	2	6	2	17	4,3	1,1
making classes more stimulating.	0	1	6	4	16	4,3	1,0
increasing student motivation.	0	2	5	4	16	4,3	1,0

Figure 5: Heatmap of responses related to the impact of games on the teaching and learning process.

To assess preferences, students rated their appreciation for each game on a five-point Likert scale (1 – disliked very much; 5 – liked very much). Results are presented in Figure 6.

Appreciation for each game	1	2	3	4	5	Mean	SD
Euclid's Regatta	0	0	3	12	12	4,3	0,7
Isommetrys in the Square	0	1	4	9	11	4,2	0,9
Mysterious symmetry	3	3	9	7	5	3,3	1,2
Problem Basket	0	1	4	10	12	4,2	0,8

Figure 6: Heatmap showing students' appreciation levels for each game.

"Euclid's Regatta" received the highest average score, followed closely by "Isometries in the Square" and "Problem Basket." In contrast, "Mysterious Symmetry" received more mixed feedback, reflected in its lower average score and higher standard deviation, suggesting a more divided reception among students. According to field notes taken by the teacher, several students found the challenges in this game too difficult, which discouraged their participation. These results indicate a general appreciation for the games overall, while also highlighting that certain formats or levels of complexity may resonate more effectively with students than others.

7.2 Use of Origami in Class

The third section of the questionnaire explored the use of origami activities. Students again expressed high levels of appreciation, as shown in Figure 7, with no negative responses.

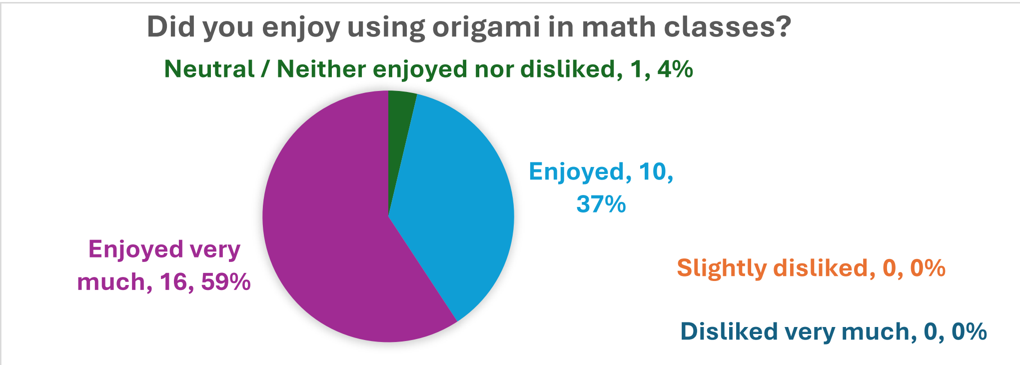

Figure 7: Pie chart of responses for the question "Did you enjoy using origami in math class?"

Next, students were asked whether they considered the use of origami to be relevant in the teaching and learning of Mathematics. Most students (93%) responded affirmatively, while one student (4%) selected "Indifferent" and another answered "No." When asked whether they would recommend using origami in math classes, 96% of students responded affirmatively, and only one student (4%) answered "No."

Students rated their agreement with statements regarding the impact of origami activities using the same five-point Likert scale. Results are presented in Figure 8. As with the games, students agreed that origami helped make learning more interactive and engaging. Although the average scores were slightly lower than for games, all means were still above 4, indicating overall positive experiences.

The use of origami in maths classes contributed to:	1	2	3	4	5	Mean	SD
making learning more interactive.	0	2	6	6	13	4,1	1,0
making classes more stimulating.	0	2	5	7	13	4,1	1,0
increasing student motivation.	0	2	7	6	12	4,0	1,0

Figure 8: Heatmap of responses related to the use of origami in maths classes.

Students also rated their appreciation for each origami activity (see Figure 9).

Appreciation for each origami activity	1	2	3	4	5	Mean	SD
Euclid's boat	0	0	2	8	16	4,5	0,6
Greenhouses	0	1	4	10	11	4,2	0,8
The Fraction fish	0	0	3	10	13	4,4	0,7

Figure 9: Heatmap showing students' appreciation levels for each origami activity.

Among the three origami tasks, "Euclid's Boat" was the most appreciated, followed closely by "Fractions Fish" and "Greenhouse." All activities received high ratings with low standard deviations, indicating widespread approval.

8. Conclusions

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

The activities allowed students to interact with mathematical concepts in a meaningful, playful, and collaborative way. Furthermore, as future teachers, participants recognised the pedagogical potential of these strategies, both for reinforcing their own learning and for enriching their future classroom practices.

Overall, the integration of games and origami into mathematics education proved to be an effective and well-received approach to promoting active learning and conceptual understanding.

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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 university (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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