European Journal of Science and Mathematics Education, 2025, **13**(1), 16-26
ISSN: 2301-251X (Online)

Research Article

Fostering creative and critical thinking through math games: A case study of Bachet's game

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Citation: Applebaum, M. (2025). Fostering creative and critical thinking through math games: A case study of Bachet's game. *European Journal of Science and Mathematics Education, 13*(1), 16-26. https://doi.org/10.30935/scimath/15825

ARTICLE INFO

Received: 17 Aug 2024

Accepted: 7 Nov 2024

ABSTRACT

Students often perceive mathematics as a challenging and abstract subject, leading to disengagement and anxiety. To address these challenges, educators have increasingly turned to math games as a pedagogical tool to make learning more interactive and enjoyable. This paper explores the potential of math games, particularly Bachet's game, as catalysts for both creative and critical thinking among pre-service teachers (PSTs). By analyzing several adaptations and variations of Bachet's game created by PSTs, the study demonstrates how these games can foster creative problem-solving skills, strategic thinking, and collaborative learning. The findings suggest that when PSTs are encouraged to modify game rules and environments, they engage in deeper mathematical inquiry and develop flexible, innovative approaches to problem-solving. The paper concludes with a discussion on the benefits, challenges, and pedagogical implications of integrating math games into the curriculum to enhance creativity and critical thinking in mathematics education.

Keywords: math games, critical thinking, creative thinking

INTRODUCTION

In an era where creative problem-solving is increasingly valued across all disciplines, finding effective ways to cultivate these skills in mathematics is crucial. Math games offer a unique opportunity to integrate creativity into mathematics education, providing a bridge between abstract concepts and practical applications. Mathematics is a fundamental subject in education, yet students often perceive it as difficult, abstract, and disconnected from real-life experiences. This perception can lead to anxiety, disengagement, and poor academic performance. To address these challenges, educators have increasingly turned to math games as a pedagogical tool to make learning mathematics more interactive, engaging, and enjoyable. Critical thinking is a cornerstone of effective mathematics education, essential for preparing students to tackle complex, real-world problems (Applebaum, 2015). Math games, particularly those that challenge students to modify rules or explore different strategies, offer a unique opportunity to foster these critical thinking skills in a playful and engaging context. These games help bridge the gap between abstract theory and practical application by encouraging students to engage deeply with mathematical concepts. Math games offer a dynamic way to involve students in hands-on activities encouraging exploration, collaboration, and creative problem-solving. In this paper, we present several math games, focusing on Bachet's game, and discuss how they can foster creativity among pre-service teachers (PSTs) by allowing them to experiment with mathematical concepts in a playful and flexible environment.

While many studies focus on the benefits of school students playing educational games, this study shifts the focus to PSTs, who were encouraged to modify and create their own versions of Bachet's game. This process not only allowed them to develop their own creative and critical thinking but also prepared them to apply these strategies in their future classrooms with school students.

This study involved PSTs who, through the design and adaptation of Bachet's game, enhanced their creative and critical thinking. An original contribution of this study is that PSTs were not only participants in game-based learning but were also tasked with designing and adapting the games themselves. This process allowed them to experience first-hand how these tools can foster creativity and critical thinking, while also preparing them to apply these strategies in their future teaching practices. The teacher in this context refers to the facilitator who guided and provided feedback during the activities.

Integration of Learning Games into Mathematics Education

The use of learning games in mathematics education is increasingly recognized as a powerful pedagogical tool. According to a systematic review by Pan et al. (2022), learning games are highly effective in aligning with curriculum standards while also promoting deeper engagement with mathematical concepts. This alignment is critical, as it ensures that the games not only entertain but also educate, reinforcing key mathematical skills and concepts through interactive play. This supports the constructivist approach, where students actively construct knowledge by interacting with the game's mechanics and applying mathematical principles in a simulated environment. These tools foster creative problem-solving and enhance the overall learning experience by allowing students to experiment, hypothesize, and iterate within the game's framework. Constructivism, as articulated by scholars like Piaget and Vygotsky, suggests that learning occurs most effectively when students are actively involved in the learning process, rather than passively receiving information. This active engagement is not only key to understanding mathematical concepts but also to fostering creative thinking, as students explore multiple pathways to solutions.

While much of the existing literature emphasizes the benefits of students playing math games, this study explores a less examined but equally valuable approach: having PSTs design and adapt math games. By creating their own versions of Bachet's game, PSTs engaged in deeper mathematical inquiry and critical reflection, gaining insights not only into game mechanics but also into the pedagogical value of such tools. This hands-on design process fosters creativity and helps future educators understand how to integrate these strategies into their own teaching.

Math games embody this constructivist approach by engaging students in hands-on, interactive activities that require them to apply mathematical concepts in a playful context. These games provide opportunities for students to experiment, hypothesize, and iterate–processes that are fundamental to creative problem-solving. For instance, Applebaum and Freiman (2014) highlight the use of strategy games like Bachet's game, named after the French mathematician Claude Gaspar Bachet de Méziriac (1581–1638), who in 1612 published a book of recreational mathematical problems entitled *Problèmes plaisants et délectables qui se font par les nombres*. These games stimulate mathematical thinking and support the construction of new knowledge. Through inquiry-based learning, students pose questions, conduct experiments, formulate hypotheses, and validate their findings, deepening their understanding and encouraging the development of innovative strategies.

Benefits of Using Math Games in the Classroom

The benefits of incorporating math games into the classroom are numerous and significant. One of the most compelling advantages is the marked increase in student motivation and engagement. Traditional mathematics instruction, which often relies heavily on lectures and repetitive exercises, can be perceived as tedious and uninspiring. In contrast, math games introduce elements of fun, competition, and exploration, transforming the learning experience from a chore into an enjoyable and dynamic activity.

Research by Orim and Ekwueme (2011) underscores that games can make mathematics more accessible and enjoyable by providing a context in which students can practice mathematical skills without the pressure of formal assessments. This shift in focus–from performance to play–reduces the anxiety commonly associated with math, particularly for students who struggle with the subject. By reducing this anxiety, math games create a more positive and relaxed learning environment, which encourages students to engage more fully with the material and to explore mathematical concepts creatively.

Moreover, math games are powerful tools for promoting critical thinking and strategic planning skills. Games like Bachet's game require students to think ahead, anticipate their opponent's moves, and develop strategies to succeed. These strategic skills are directly transferable to traditional mathematical problem-solving, where students must analyze problems, evaluate different approaches, and select the most effective solutions. The ability to think strategically and creatively in the context of a game enhances students' capacity to tackle more complex mathematical tasks.

Another significant benefit of math games is their capacity to support differentiated instruction. In any classroom, students arrive with varying levels of mathematical ability and understanding. Math games can be tailored to meet these diverse needs by adjusting the difficulty level, modifying the rules, or focusing on different mathematical concepts. This flexibility allows educators to provide a more personalized learning experience, which can lead to improved outcomes for all learners. Furthermore, the collaborative nature of many math games fosters a classroom culture where students learn from and support each other, further enhancing the creative and critical thinking skills of the entire group.

All the above-mentioned benefits, in turn, create a fertile environment for creative thinking, making math games an invaluable tool in the modern mathematics classroom.

Challenges and Constraints in Implementing Math Games

While the benefits of using math games in the classroom are well-documented, several challenges and constraints must be carefully considered to ensure their successful implementation. One of the primary challenges is the perception among some educators that games are not a serious or effective method of teaching mathematics. Orim and Ekwueme (2011) note that some teachers view the use of games as a distraction from the "serious" work of learning mathematics, particularly in contexts where high-stakes testing and curriculum coverage are prioritized. This perception can significantly limit the adoption of games as a teaching tool, especially in schools where traditional methods are deeply entrenched. Overcoming this challenge requires a shift in mindset, where educators recognize the value of games as a legitimate and powerful tool for enhancing mathematical understanding and creativity.

Another significant challenge is the lack of resources and training available to teachers on how to effectively implement math games in the classroom. Many teachers may not have access to a wide variety of games or may be unfamiliar with how to integrate them into their existing curriculum. This lack of familiarity can lead to a reluctance to use games, as teachers may feel uncertain about how to manage gameplay, assess student learning, or align games with curricular goals. Addressing this challenge requires targeted professional development programs that equip teachers with the necessary skills and knowledge to incorporate math games effectively into their teaching practice.

Additionally, the varying levels of student ability can present difficulties when using math games. Research by Song et al. (2007) indicates that while higher-level students may excel in game-based tasks, lower-level students may struggle to keep up. For example, in strategy games like NIM (Chinese version of Bashet's game), higher-level students are more likely to engage in complex problem-posing and restructuring, while lower-level students may only modify one or two components of the game intuitively without fully understanding the underlying mathematical concepts. This discrepancy highlights the need for careful selection and adaptation of games to ensure that all students can benefit from the learning experience. Providing differentiated support and selecting games with adjustable difficulty levels can help mitigate these challenges.

Finally, time constraints and curriculum demands can also limit the use of math games. Teachers may feel that there is not enough time to incorporate games into their lessons, particularly when they are under pressure to cover a wide range of topics within a limited timeframe. This challenge is compounded by the need to balance the use of games with other instructional methods, such as direct instruction, practice exercises, and assessments. To address this, educators could consider integrating games as a complement to traditional methods, using them to reinforce key concepts or as a form of formative assessment.

Addressing these challenges is crucial for unlocking the full potential of math games in the classroom. By overcoming these barriers, educators can create a more dynamic and creative learning environment that not only enhances students' mathematical skills but also fosters the development of innovative thinking.

Empirical Evidence on Math Games and Creativity

Empirical studies provide robust support for the role of math games in fostering creative thinking among students. These studies demonstrate that when students engage in math games, they not only deepen their mathematical understanding but also enhance their ability to think creatively and solve problems in novel ways.

For instance, Shriki (2009) conducted research on the impact of strategy games like NIM on students' creative thinking abilities. The study highlighted that these games encourage students to generate algebraic patterns and engage in creative problem-solving. Shriki (2009) found that as students play these games, they naturally begin to explore various strategies, leading to the discovery of novel mathematical insights and solutions. This process of exploration and strategy development is a key aspect of creative thinking, as it requires students to go beyond conventional approaches and invent new methods for success.

Similarly, a study by Applebaum (2015) examined the impact of Bachet's game on students' ability to engage in mathematical investigations. The study revealed that students who regularly played this game developed a stronger capacity for posing creative problems, generating hypotheses, and exploring multiple solutions. This process of inquiry and exploration is central to creative thinking, as it pushes students to think beyond standard procedures and consider alternative approaches. The study provides compelling evidence that structured gameplay can be a powerful tool in cultivating creativity within the mathematics classroom.

Additionally, the "what if not?" strategy, as discussed by Song et al. (2007), underscores the creative potential of modifying math games. This strategy challenges students to alter game parameters and invent new problems, thereby encouraging them to break free from rigid thinking patterns and explore a broader range of possibilities. By engaging in creative problem-posing, students develop the flexibility and innovation that are essential for success in both mathematical and real-world contexts.

These studies collectively highlight the significant potential of math games to act as catalysts for creative thinking. By fostering an environment where exploration, hypothesis generation, and strategy development are encouraged, math games enable students to develop the creative skills necessary for success in mathematics and beyond.

Benefits of Math Games for Creative Thinking

The integration of math games in the classroom offers a range of benefits that significantly contribute to the development of creative thinking among students. These games create a dynamic learning environment where students are encouraged to explore, experiment, and innovate, leading to the following key benefits:

1. **Encouraging divergent thinking:** Math games often present problems that can be approached in multiple ways, encouraging students to explore different strategies and solutions. This divergent thinking is a cornerstone of creativity, as it involves generating a variety of ideas and considering multiple approaches to a problem. For example, in games like Bachet's game, students must think strategically about their moves, leading them to discover new and creative ways to outmaneuver their opponents.
2. **Reducing math anxiety:** Creativity flourishes in environments where students feel safe to experiment and take risks. Math games, by making learning more enjoyable and less formal, help reduce the anxiety often associated with math learning. This stress reduction allows students to engage more fully with the material and take the creative risks necessary to develop innovative solutions. For instance, the playful nature of games like NIM can make challenging mathematical concepts more accessible and less intimidating.
3. **Promoting collaboration and communication:** Many math games involve group play, requiring students to communicate their ideas and strategies with peers. This collaborative environment not only enhances creative thinking but also helps students develop crucial social and communication skills. Through discussion and teamwork, students are exposed to diverse perspectives, which can spark new ideas and foster a more creative approach to problem-solving.
4. **Developing problem-solving skills:** Creative thinking in mathematics is closely linked to problem-solving. Math games challenge students to apply their knowledge in novel ways, encouraging them to think critically and creatively to overcome challenges. Whether working through a complex strategy in a game or devising a new approach to an old problem, students develop the ability to think on their feet and adapt their strategies, which are essential skills for creativity.

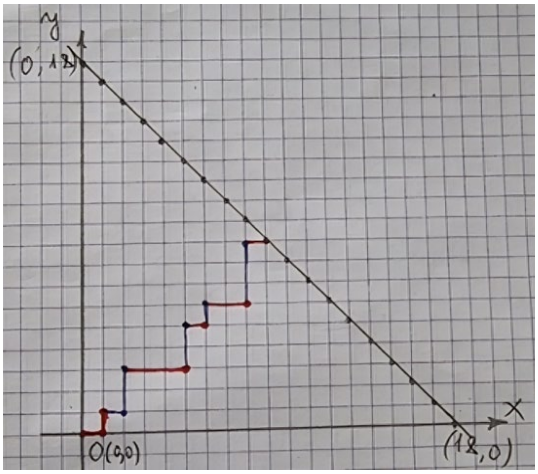

Figure 1. Protocol of game N1 (Source: Author)

Collectively, these benefits illustrate how math games can serve as powerful tools for fostering creativity in the classroom. By encouraging divergent thinking, reducing anxiety, promoting collaboration, and enhancing problem-solving skills, math games help students develop the creative mindset necessary for success in mathematics and beyond.

Game Design and Learning Outcomes

The design of learning games plays a crucial role in achieving specific educational outcomes. The systematic review highlights that well-designed games are those that embed mathematical problems within engaging narratives or challenging scenarios, thereby encouraging students to apply their knowledge in innovative ways. This reinforces the importance of constructivist principles in game design, where the learning process is student-centered and exploratory. Games like Bachet's game, when adapted by students or teachers, exemplify this approach, offering a rich environment for creative exploration and cognitive development.

In the next chapter, we present several games designed by PSTs during problem-solving classes conducted over different years. All these games are based on the original Bachet's game[1], which was presented and discussed by the PSTs in previous lessons.

FOLLOWING BACHET'S GAME

After PSTs became familiar with the articles on Bachet's games, they were asked to create a new version of Bachet's game, either by changing the rules or modifying the environment. They were then required to test and analyze the new game to find a "win strategy" and present it to their peers.

The PSTs worked in small groups for about half an hour, and their examples are presented below.

Group N1's Game (Game N1)

The game is played on a coordinate grid. The first player starts at the origin (0, 0) and must move solely along the grid lines, either to the right or upwards. Each player should start from the point where the previous player stopped. On each turn, a player can move either 1, 2, or 3 units. The player who first reaches a specific line ($y = -x + 18$) loses the game. The task is to find a "win strategy."

This group presented (**Figure 1**) the following protocol for playing the game. According to the protocol, the player who starts (marked in red) loses the game.

The "win strategy" suggested by the PSTs involves the following logic: The total distance from the origin to the marked points on line $y = -x + 18$ is 18 units. The rules of this game are analogous to those in the original

[1] Fifteen tokens are placed on the board. The game is played by two players: the first player begins by removing one, two, or three tokens, followed by the second player removing one, two, or three tokens. The process repeats, with the first player again removing up to three tokens, and so on. The player who is forced to pick up the last token loses the game.

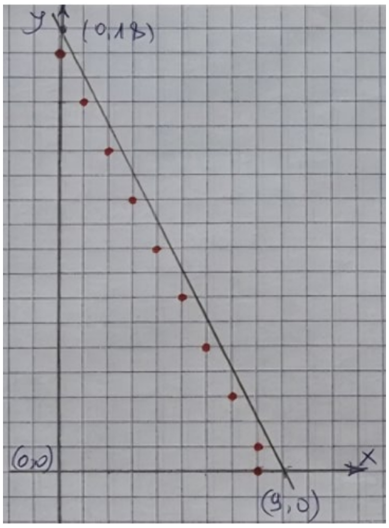

Figure 2. Protocol of game N2 (Source: Author)

Bachet's game, which was: to reduce the total number of tokens (in our example of distance) by one: (*N* – 1). Then divide (*N* – 1) by (*k* + 1). If there is a remainder (1, 2, 3, ..., or *k*) then the result of the game depends only on the first player, and he can win the game. If there is no remainder then the second player can win the game by using the same strategy.

$$\frac{N-1}{k+1} = \begin{cases} whole\ number\ => the\ second\ player\ is\ the\ winner \\ some\ reminder\ => the\ first\ player\ is\ the\ winner \end{cases}$$

Then, for a player to win the game, he must complete a *k* + 1 number of tokens with the tokens taken by the other player (Applebaum & Freiman, 2014).

Realizing this strategy in game N1, first, we reduce total number of units by one: 18 – 1 = 17. Then, divide 17 by 4 (where 4 = 3 + 1). The remainder is 1, so the outcome of the game depends on the first player's use of the "win strategy" (taking the remainder–1 unit–and completing a sum of 4 units on each subsequent move).

> Teacher's feedback: "This is a brilliant idea. You've changed the environment from tokens to movement on a coordinate grid, yet the 'win strategy' remains the same. How could we modify the rules to make this game more open-ended, without a well-known 'win strategy'?"

> PST A (group N1): "What if we adjust the rules? Let's call it game N1a."

In game N1a, the players still move on the coordinate grid and must start from where the previous player stopped. Each player can move 1, 2, or 3 units, but the difference from the previous player's number of units moved should not be more than 1 unit. For example, if the previous player moved 3 units, the next player should move either 2 or 3 units. If the previous player moved 2 units, the next player should move 1, 2, or 3 units. If the previous player moved 1 unit, the next player should move 1 or 2 units. The player who first reaches the line *y* = –*x* + 18 loses the game.

> Teacher's feedback: "These new rules lead to a game without any known 'win strategy'!"

> PST B (group N1): "We could further change the game by altering the linear function's coefficients. For example, let's create game N1b with the line *y* = –2*x* + 18. The player who first reaches this line loses the game."

After analyzing this situation, the PSTs concluded that to win the game, the second player needs to reach specific points on the grid (marked in red in **Figure 2**): (0, 17), (1, 15), (2, 13), (3, 11), (4, 9), (5, 7), (6, 5), (7, 3), (8, 1), (9, 0). The distances between the origin (0, 0) and the "win-points" vary between 9 units and 17 units, making the game more complex and open-ended.

> Teacher's feedback: "This modification also creates an open-ended game strategy."

Table 1. Protocol of game N2a

Player 1	Player 2	Cup 1 (starting at 0 kg)	Cup 2 (starting at 32 kg)
4 kg to cup 1	3 kg to cup 1	7 kg	32 kg
4 kg to cup 1	2 kg to cup 1	13 kg	32 kg
3 kg to cup 1	4 kg to cup 1	20 kg	32 kg
4 kg to cup 1	3 kg to cup 1	27 kg	32 kg
1 kg to cup 2	1 kg to cup 1	28 kg	33 kg
1 kg to cup 2	1 kg to cup 1	29 kg	34 kg
1 kg to cup 2	1 kg to cup 1	30 kg	35 kg

Group N2's Game: Mathematics in the Gym (Game N2)

This game combines strategy with physical activity, making it suitable for a gym setting. The game involves a balance scale and weights.

Game rules

- On one side of the balance scale, there is a weight equal to 32 kg. The other side is initially empty.
- Two players take turns placing weights on the empty side. Each player has access to weights of 1 kg, 2 kg, 3 kg, and 4 kg.
- On each turn, a player can place only one weight on the empty side of the scale.
- The player who equalizes the scales or causes the side with the original 32 kg weight to tip loses the game.

Solution

To devise a "win strategy," the first step is to reduce 32 by one: 32 – 1 = 31. Then, divide 31 by 5 (since 5 = 4 + 1). The remainder is 1, so the result of the game depends on the first player's ability to utilize the "win strategy" (taking the remainder–1 kg–and ensuring that the sum of each move equals 5 kg).

> PST A (group N2): "How will the game change if we modify the conditions, as follows? In this game (N2a), each player still has weights of 1 kg, 2 kg, 3 kg, and 4 kg at their disposal, but they can now choose to place either 1–4 kg on the empty side of the scale or 1–2 kg on the side with the original 32 kg weight. The winner is the player who equalizes the scales."

The protocol for the suggested game is presented in **Table 1**.

The result of this game was a draw!

> Teacher's feedback: "It looks like this game doesn't have a 'win strategy' and has the potential for a draw."

> PST B (group N2): "I suggest another variation, game N2b. Let's limit the number of weights, as follows: On one side of the balance scale, there is still a 32 kg weight. The other side starts empty. Each of the two players has the following nine weights: 1 kg, 1 kg, 1 kg, 2 kg, 2 kg, 2 kg, 3 kg, 3 kg, and 3 kg. On each turn, players can place only one weight on the empty side of the scale. The player who equalizes the scales or causes the scale to tip with the 32 kg weight loses the game."

The protocol for game N2b is presented in **Table 2**.

In this variation, the second player lost.

> Teacher's feedback: "It seems that the players used the 'win strategy' from the original game: reduce 32 by one (32 – 1 = 31), then divide 31 by 4 (where 4 = 3 + 1). The remainder was 3, so the first player took the remainder (3) and completed the sum of 4 on each step until they ran out of weight. Limiting the number of weights also makes the game more open-ended".

> PST C (group N2): "To make the game more interesting, I suggest a further variation (game N2c). Let's limit the players to a set number of weights but allow them to choose their weights themselves.

Table 2. Protocol of game N2b

Player 1	Player 2	Cup 1 (starting at 0 kg)	Cup 2 (starting at 32 kg)
3 kg	3 kg	6 kg	32 kg
1 kg	3 kg	10 kg	32 kg
1 kg	3 kg	14 kg	32 kg
1 kg	1 kg	16 kg	32 kg
3 kg	1 kg	20 kg	32 kg
3 kg	1 kg	24 kg	32 kg
2 kg	2 kg	28 kg	32 kg
2 kg	2 kg	32 kg	32 kg

Each player can prepare a list of nine weights from 1 kg to 5 kg without knowing the other player's selection. The main rules remain the same: one side of the balance scale starts with 32 kg, and each player places their weights on the opposite side. The player who equalizes the scales or causes the 32 kg side to tip loses the game."

Teacher's feedback: "The new elements you added make the original problem more interesting and open-ended."

Group N3's Game: Prime Numbers (Game N3)

This game focuses on prime numbers and is designed to challenge players' understanding of basic number theory.

Game rules

- There are 25 matches placed on the table.
- Two players take turns removing matches.
- On each turn, a player may take either one match or a prime number of matches.
- The player who is forced to take the last match loses the game.

Game example

The following is a possible sequence of moves:

- 25 → 24 → 21 → 19 → 14 → 1 → 0.

In this sequence, the second player loses the game by being forced to take the last match.

Teacher's feedback: "This game introduces an interesting strategic element with prime numbers, and it also appears to be an open strategy game."

PST A (group N3): "The game can sometimes be very short, like in the next sequence (25 → 2 → 1 → 0). To extend the game, I suggest adding a new rule: In each turn, a player can only take up to half of the remaining matches."

Teacher's feedback: "That's a valuable modification–it adds complexity to the game and makes it more challenging."

PST B (group N3): "To further build on this, we could add another rule: One player selects the total number of matches at the start of the game (for example, between 50 and 60), and the second player decides whether he wants to go first. This adds a layer of strategy, similar to the approach discussed in Applebaum and Freiman's (2014) paper."

Teacher's feedback: "Your suggestion adds an exciting strategic dimension to the game. By allowing one player to choose the total number of matches and the other to decide who goes first, you're introducing a layer of psychological strategy, where players must anticipate their opponent's moves from the very start. This not only makes the game more complex but also encourages deeper critical

> thinking and planning. It's a great way to enhance the game's challenge and engage players more thoroughly."

Through the iterative process of designing, testing, and presenting games, PSTs not only refined their problem-solving skills but also reflected on how such activities could be structured to engage their future students. This reflective practice is key to helping PSTs bridge the gap between theory and classroom application.

DISCUSSION

The exploration of math games, particularly those based on Bachet's game, highlights the multifaceted role these tools play in mathematics education. The activities conducted by PSTs in this study underscore the potential of math games to go beyond simple engagement, acting as powerful catalysts for creativity, critical thinking, and collaborative problem-solving.

One of the most compelling aspects of the math games explored in this study is the emphasis on rule modification and the creation of new game variations. By allowing students to modify existing games or invent new ones, educators provide an opportunity for students to engage in divergent thinking–a key component of creativity. This process of modifying rules or changing the environment within the game mirrors real-world problem-solving, where solutions are often not straightforward and require innovative thinking. The ability to alter game parameters encourages students to experiment, hypothesize, and explore multiple outcomes, which are essential skills in both mathematical inquiry and broader cognitive development.

The group-based nature of the activities also emphasizes the importance of collaboration in learning. Math games, when played in groups, require students to articulate their thoughts, listen to others' ideas, and work together to develop strategies. This collaborative environment fosters communication skills and helps students learn from one another, leading to a deeper understanding of mathematical concepts. The discussions and debates that arise during gameplay are instrumental in helping students refine their thinking and approach problems from different angles. This mirrors professional environments where teamwork and the ability to communicate complex ideas effectively are crucial.

The findings from Russo et al.'s (2021) study on how primary teachers use games in mathematics education further support the role of math games in fostering student engagement and creativity. The study reveals that teachers frequently use games not only as a tool for practicing mathematical fluency but also to introduce new concepts and energize the classroom atmosphere. These findings suggest that math games are a versatile instructional tool, capable of engaging students at multiple levels of understanding. By integrating games into their teaching, educators can create a dynamic learning environment where creativity is nurtured through interactive, hands-on activities.

Moreover, the empirical data from Russo et al.'s (2021) research indicate that teachers perceive games as highly effective in supporting differentiated instruction. This aligns with the findings from our study, where PSTs were able to adapt games to meet the varying needs of their students. The ability to tailor games to different learning styles and abilities not only enhances engagement but also provides a fertile ground for creative thinking. Students are encouraged to approach problems from multiple perspectives, fostering the development of innovative solutions.

The findings from this study align with those of Applebaum (2015), who demonstrated that critical thinking skills can be significantly enhanced through targeted problem-solving activities in mathematics. Just as PSTs benefited from examining different problem-solving strategies, students who engage with math games can develop similar skills by exploring various approaches to game-based challenges. This suggests that math games not only foster creativity but also cultivate the critical thinking necessary for deeper mathematical inquiry.

The systematic review (Pan et al., 2022) provides robust empirical evidence supporting the effectiveness of learning games in enhancing various mathematical skills, such as problem-solving, algebra, and mental computation. These findings resonate with the results observed in the activities conducted by PSTs in this study. The games designed and tested by the PSTs not only engaged students but also significantly enhanced their mathematical understanding and creative thinking skills. This empirical support strengthens the argument that math games are not merely supplementary tools but integral components of a comprehensive mathematics curriculum.

While the benefits of math games are well-documented, it is important to consider the potential limitations of relying too heavily on game-based learning. Balancing games with traditional instructional methods is crucial to ensure that foundational mathematical skills are effectively developed. This balanced approach allows students to benefit from the engagement and creativity fostered by games while also reinforcing the core mathematical concepts that are essential for long-term academic success.

Despite the clear benefits, the implementation of math games in the classroom is not without challenges. As discussed, one significant barrier is the perception among some educators that games are not a serious method of teaching mathematics. Overcoming this challenge requires a shift in educational philosophy, where games are recognized as valuable tools for enhancing mathematical understanding and fostering creativity. Additionally, the lack of resources and training available to teachers presents a significant constraint. Many educators may feel ill-equipped to integrate games into their teaching practice, particularly if they are unfamiliar with how to align these activities with curriculum goals and learning outcomes.

Russo et al.'s (2021) study also highlights challenges teachers face, such as managing game-related tasks and ensuring that mathematical concepts remain central to gameplay. This finding underscores the need for careful planning and execution when incorporating games into the classroom. Teachers must strike a balance between maintaining the educational focus of the game and allowing for the creative exploration that makes these activities so valuable.

Pan et al. (2022) also highlight several challenges associated with their implementation. One key challenge is ensuring that the game content is well-aligned with educational objectives and accessible to all students, regardless of their skill level. This aligns with the challenges discussed in this paper, where the diversity in student abilities posed difficulties in ensuring that all learners could benefit equally from the games. The review underscores the importance of careful game selection and design to address these challenges, suggesting that teachers need to be well-versed in both the educational content and the technical aspects of the games they use.

The pieces of evidence presented in this paper supports the notion that math games are effective tools for fostering higher-order thinking skills. Studies such as those by Shriki (2009) and Applebaum and Freiman (2014) demonstrate that students who engage in math games develop stronger abilities in creative problem-solving, hypothesis generation, and strategic planning. These skills are not only crucial for success in mathematics but are also transferable to other academic disciplines and real-world situations.

The game design process not only enhanced PSTs' creative and critical thinking but also provided a reflective framework for them to understand how they could use these strategies in their future classrooms, encouraging them to critically evaluate their teaching approaches. By engaging in rule modification and game-based problem-solving, PSTs were able to envision how such games could be used to foster similar skills in their future students, thereby aligning their own learning with their teaching practice.

However, it is important to consider the long-term impact of these games on student learning outcomes. While the immediate benefits of engagement and creativity are clear, further research is needed to explore how these skills develop over time and how they influence students' overall academic performance and problem-solving abilities. Additionally, the role of teacher facilitation in maximizing the effectiveness of math games warrants further investigation. The ability of the teacher to guide, challenge, and support students during gameplay is likely a critical factor in the success of these activities.

CONCLUSION

In conclusion, math games, particularly those inspired by Bachet's game, offer a promising approach to enhancing creativity, critical thinking, and problem-solving skills in mathematics education. The activities designed and tested by PSTs in this study demonstrate how these games can be adapted to foster a deeper understanding of mathematical concepts while simultaneously encouraging students to think creatively and collaborate effectively.

The benefits of using math games in the classroom are clear: they engage students in a playful and interactive learning process, reduce math anxiety, promote divergent thinking, and develop essential cognitive skills. However, to fully realize these benefits, educators must address the challenges associated with their implementation. These challenges include changing perceptions about the educational value of games, providing adequate training and resources for teachers, and ensuring that games are accessible and beneficial to students of all ability levels.

Future research should focus on optimizing game design to cater to diverse learners, ensuring that games are both challenging and accessible, and continuing to explore the long-term effects of math games on student learning and creativity. Understanding how these games contribute to sustained academic growth and the development of transferable skills is crucial for informing best practices in mathematics education. Additionally, professional development programs that equip teachers with the knowledge and skills to integrate math games into their curricula effectively will be essential for overcoming the challenges discussed in this paper. A key contribution of this study is the innovative focus on PSTs designing and adapting math games, which allowed them to directly engage with mathematical concepts and pedagogical strategies, rather than merely playing them. This approach provided PSTs with a deeper understanding of how games can be used as pedagogical tools, equipping them with the skills to foster creativity and critical thinking in their future classrooms.

Ultimately, math games represent a dynamic and innovative approach to mathematics education, enhancing PSTs' skills and preparing them to transfer these methods to their future students. By tailoring game-based activities to the unique dynamics of their classrooms, future teachers can maximize the educational benefits of these tools and foster a more creative and engaging learning environment. Moreover, as highlighted in studies like those of Applebaum (2015), integrating math games into the curriculum supports creativity and engagement and the development of critical thinking skills. By fostering exploration, creativity, and collaboration in the classroom, educators can help students develop the critical thinking and creative problem-solving skills essential for success in the 21st century.

Funding: The author received no financial support for the research and/or authorship of this article.

Ethics declaration: Based on the scope and methodology of the study, ethical approval is not required under the guidelines of Kaye Academic College of Education. This is because the study did not involve sensitive personal data, or interventions requiring ethical oversight.

Declaration of interest: The author declared no competing interest.

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

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