

# Designing Educational Games as a Learning Experience for Pre-service Mathematics Teachers

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**Abstract:** The design of educational games represents a promising approach to engaging pre-service teachers in active learning about mathematics teaching. Rather than relying solely on ready-made games, the process of designing educational games may foster deeper reflection on mathematical content, student learning, and instructional design. Through the process of creating a game, pre-service mathematics teachers must consider not only the mathematical concepts to be addressed but also the rules, structure, and dynamics that support meaningful learning through play. Such design activities may therefore serve as opportunities for developing pedagogical and didactic thinking during teacher preparation. This paper explores how pre-service mathematics teachers perceive the experience of designing educational games as part of their teacher education at the Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava. The participants were university students enrolled in a mathematics teacher preparation program who had designed an educational game intended for teaching mathematics at the lower or upper secondary school level. The participants engaged in designing educational games during the course Game-Based Mathematics Teaching. Data were collected through an open-ended questionnaire that invited participants to reflect on their experiences during the design process, including the challenges they encountered, the decisions they made, and what they believed they had learned from the activity. The responses were analyzed using thematic analysis in order to identify recurring themes in students' reflections on the design process and its perceived educational value. The study aims to contribute to a better understanding of how designing educational games can function as a learning experience in the preparation of pre-service mathematics teachers and how such activities may support reflection on instructional design and student learning. The findings provide insights into the potential of game design activities as a component of mathematics teacher education and inform the integration of similar design-based learning tasks into teacher preparation programmes.

**Keywords:** Game-based learning, Pre-service teacher education, Innovative teaching methods, Game design

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## 1. Introduction

Game-based learning has become an important topic in contemporary educational research and practice. In mathematics education, games are often discussed as a way of supporting pupils' active participation, motivation, problem solving, and positive attitudes towards mathematics. However, the educational value of games does not follow automatically from their playful form. A game used in school mathematics needs to be connected with clearly defined educational goals, appropriate mathematical content, understandable rules, and meaningful activity of learners. This understanding is consistent with the view that game-based learning involves the use of games with defined educational goals, while preserving the attractiveness of the game activity (Vankúš, 2013, 2023).

The potential of games in education has been associated with engagement, exploration, interaction, motivation, and knowledge construction. Nevertheless, several authors emphasize that the successful use of games in teaching depends strongly on the role of the teacher. The teacher is not merely a person who introduces a game into the classroom. Rather, the teacher connects the game with learning goals, facilitates discussion and reflection, identifies teachable moments, and helps pupils understand the relevance of what they experience during gameplay (Molin, 2017). Foster and Shah (2020) similarly argue for the centrality of teachers in game-based learning and emphasize that teachers play an active role in game-based learning environments, that games are not pedagogically neutral, and that teachers' knowledge of game-based learning develops over time.

These arguments have important implications for teacher education. If future teachers are expected to use educational games meaningfully, they need opportunities to understand both the potential and the limitations of games as learning tools. Becker (2007) argues that teachers cannot be expected to embrace games for learning without confidence in their own ability to use them effectively and without a sound understanding of their possibilities and constraints. Similarly, Foster and Shah (2020) point out that although pre-service teachers may hold positive views about games, their understanding of how to implement them in the curriculum may remain limited. Teacher education should therefore provide opportunities not only to experience games, but also to analyse, adapt, and design them in relation to specific learning goals and classroom conditions.

One promising way to develop such understanding is to involve pre-service teachers in the design of their own educational games. Designing a game requires more than selecting a playful format. It involves decisions about mathematical content, target age group, rules, tasks, game mechanics, materials, difficulty, collaboration, competition, and the ways in which pupils are expected to engage with mathematical ideas. From this perspective, the design of an educational game can become a learning experience for pre-service teachers themselves. It may encourage them to transform mathematical content into tasks, consider pupils' prior knowledge and possible difficulties, formulate questions clearly, and reflect on the relationship between learning goals and game structure.

Previous research on game-based learning in teacher education suggests that such experiences can support active learning, creativity, collaboration, motivation, and educational innovation. For example, Cózar-Gutiérrez and Sáez-López (2016) found that game-based learning and gamification in initial teacher training were positively associated with activity, engagement, motivation, and innovation. At the same time, studies on the implementation of game-based learning point to the need for teacher preparation, pedagogical support, and attention to contextual conditions such as time, resources, school culture, and teacher confidence (Ketelhut & Schifter, 2011). These findings support the view that game-based learning should be addressed in teacher education not only as a classroom method for pupils, but also as a professional learning area for future teachers.

Although research has examined the educational potential of game-based learning and the need to prepare teachers for its meaningful implementation, the teacher's role has traditionally been underrepresented in this field. Moreover, only a limited number of studies have focused on pre-service teachers' knowledge of GBL and on the processes involved in teaching with games, while fewer studies have allowed them to apply this knowledge in designing learning activities. This suggests a research gap concerning how pre-service mathematics teachers perceive the process of designing their own physical educational games (Molin, 2017; Foster & Shah, 2020; Ketelhut & Schifter, 2011).

The present study explores how pre-service mathematics teachers perceived the experience of designing their own physical educational game as part of the course Game-Based Mathematics Teaching at the Faculty of Mathematics, Physics and Informatics, Comenius University Bratislava. The study focuses on participants' reflections on the design process, the enjoyable and demanding aspects of the activity, and the ways in which they considered mathematical content and pupils' needs. The study is guided by the following research questions:

*RQ1. How do pre-service mathematics teachers perceive the experience and process of designing their own physical educational game for mathematics teaching?*

*RQ2. Which aspects of the design process do pre-service mathematics teachers describe as enjoyable, demanding, or educationally valuable?*

*RQ3. How do pre-service mathematics teachers reflect on mathematical content, pupils' needs, and classroom feasibility when designing an educational game?*

By analysing pre-service teachers' reflections, the paper aims to contribute to a better understanding of educational game design as a learning experience in mathematics teacher education. It also seeks to show how the process of designing a physical educational game may support future teachers in connecting mathematical content, learner-oriented thinking, instructional design, and the practical conditions of classroom use.

## **2. Methodology**

The study was designed as an exploratory qualitative study with a descriptive component. Its aim was to examine how pre-service mathematics teachers perceived the process of designing an educational game for mathematics teaching. The main analytical approach was qualitative thematic analysis, which was used to identify recurring patterns in participants' reflections on the design process, the challenges they encountered, the decisions they made, and the learning they associated with the activity. The research was conducted in the context of the university course Game-Based Mathematics Teaching. During the semester, students attended the course once a week for two teaching hours. As part of the course, they were asked to design an educational game intended for mathematics teaching at the lower or upper secondary school level. During the course, students create several types of educational games. In the first semester, they design a digital educational escape room in Google Forms and another using the Escape Room Maker tool. In the second semester, they create a physical board game, usually consisting of a game board and cards.

## 2.1 Participants and Context

The participants were 13 pre-service mathematics teachers enrolled in the course Game-Based Mathematics Teaching. The course focused on the use of games in mathematics education and provided students with an opportunity to create their own educational games as part of their preparation for future teaching practice. The course is an elective subject in the bachelor's program and it consists of two hours of instruction per week and is available to first-year students in both the winter and summer semesters.

Throughout the semester, students worked on the development of an educational game for mathematics teaching. They selected a mathematical topic or idea, considered the target group of pupils, designed the structure and rules of the game, created mathematical tasks or questions, and prepared the necessary game materials. The games were intended to support meaningful engagement with mathematics and to be usable, at least in principle, in lower or upper secondary mathematics lessons.

The design task required students to connect mathematical content with gameplay, learner activity, and classroom conditions. In this sense, the activity was treated not only as the production of a final game, but also as a process through which pre-service teachers could reflect on the relationship between mathematical content, pupils' needs, and instructional design.

## 2.2 Data collection and Analysis

Data were collected through an open-ended questionnaire administered after the students had worked on the design of their educational games. The questionnaire was created in Google Forms and introduced to participants as a research instrument. Participants were informed that the form served to collect data for research purposes, that all responses would be processed anonymously, and that the data would be used exclusively for research purposes. By completing the questionnaire, participants gave consent for their anonymised responses to be used in the study.

The questionnaire consisted of the following open-ended questions, showed in Table 1.

**Table 1: Items of the questionnaire**

|     |                                                                                                                             |
|-----|-----------------------------------------------------------------------------------------------------------------------------|
| 1.  | How would you describe your overall experience with designing an educational game for mathematics teaching?                 |
| 2.  | How did the design of your game proceed from the initial idea to the final version? Briefly describe the individual stages. |
| 3.  | What did you enjoy most when designing the game, and why?                                                                   |
| 4.  | What was the most demanding aspect of designing the game, and why?                                                          |
| 5.  | Did you change any parts of the game during the design process?<br>If yes, what did you change and why?                     |
| 6.  | Why did you choose this particular mathematical topic or idea for your game?                                                |
| 7.  | Did designing the game influence how you selected the mathematical content you wanted to teach? If yes, how?                |
| 8.  | What did you have to consider in order to make the mathematical content understandable and meaningful for pupils?           |
| 9.  | What do you think you learned while designing an educational game?                                                          |
| 10. | Can you imagine creating your own educational games in your future teaching practice? Why or why not?                       |

The open-ended responses were analysed using qualitative thematic analysis. This approach was chosen because the aim of the study was to identify and interpret recurring patterns of meaning in participants' reflections on the process of designing educational games. The analysis focused on how participants described their overall experience, the stages of the design process, enjoyable and demanding aspects of the activity, perceived learning outcomes, and their reflections on mathematical content, pupils' needs, and classroom feasibility.

The analysis proceeded in several steps. First, all responses were read repeatedly in order to become familiar with the data. Second, meaningful segments of the responses were identified and coded with respect to the

research questions. Third, related codes were compared and grouped into broader themes. These themes were then reviewed and refined in relation to the full dataset and the aims of the study.

The analysis was primarily inductive, as the themes were developed from the participants' responses. At the same time, the interpretation was guided by the focus of the study on educational game design as a learning experience in mathematics teacher education.

### 3. Results

The results are organized according to the three research questions. Section 3.1 addresses RQ1 by examining participants' perceptions of the experience of designing an educational game; Section 3.2 addresses RQ2 by focusing on enjoyable, demanding, and educationally valuable aspects; and Section 3.3 addresses RQ3 by analyzing reflections on mathematical content, pupils' needs, and classroom feasibility.

#### 3.1 Perceiving Educational Game Design as a Positive and Multi-stage Process

Participants described designing an educational game for mathematics teaching as a positive and engaging experience. Their responses suggest that they perceived the activity as enjoyable, meaningful, and different from more traditional academic tasks. Several participants emphasized that the process allowed them to use not only their mathematical thinking, but also creativity, collaboration, and personal initiative. One participant wrote that they enjoyed "thinking of tasks for pupils, solving them, and giving the game a nice form so that it could later be used in lessons." These responses indicate that the activity was generally approached with enthusiasm and openness.

Participants' descriptions also suggest that the design of the game was experienced as a multi-stage process rather than a single creative act. In some cases, the initial idea appeared suddenly and intuitively. In other cases, the process began with uncertainty and gradual exploration, for example when participants described that at first, they did not know how to proceed, and only later found inspiration in an already existing game.

At the same time, the responses show that the design process involved both creative and organizational dimensions. Participants mentioned brainstorming possible ideas, deciding whether the game would be competitive or cooperative, card-based or board-based, and discussing what components would make it distinctive. Some groups also explicitly referred to dividing responsibilities, such as checking the correctness of questions, preparing the technical elements, or designing the game board. Taken together, these responses indicate that the activity required not only inventiveness, but also planning, negotiation, and practical coordination. A summary of the stages identified in participants' accounts is presented in Table 2.

**Table 2: Stages of the educational game design process described by participants**

| Stage                      | Description based on participants' responses                          | Illustrative quote                                             |
|----------------------------|-----------------------------------------------------------------------|----------------------------------------------------------------|
| Initial idea               | spontaneous idea, brainstorming, or inspiration from an existing game | <i>"like a bolt from the blue"</i>                             |
| Concept development        | refining the main idea and deciding on the overall format of the game | <i>"at first we did not know, then we started thinking"</i>    |
| Structural decisions       | choosing mechanics, rules, type of game, and target age group         | <i>"competitive/cooperative, dice/card"</i>                    |
| Division of work           | allocating responsibilities within the group                          | <i>"we divided tasks and responsibilities"</i>                 |
| Content creation           | creating questions, tasks, and mathematical content                   | <i>"the most difficult part was creating the questions"</i>    |
| Material and visual design | preparing cards, the board, colours, and visual elements              | <i>"working on the visual form of the game"</i>                |
| Finalization               | revising details and preparing the final version                      | <i>"now we are just inventing tasks and finishing details"</i> |

### **3.2 Enjoyment, Challenges, and Learning Through the Design Process**

A strong theme across the responses was the contrast between the enjoyable and the demanding aspects of the activity. What participants appreciated most was often connected with creativity, collaboration, and the opportunity to shape the game in an original way. Several respondents highlighted cooperation with peers and the exchange of ideas as particularly enjoyable. One participant referred to “cooperation with the girls and inventing mathematical tasks,” while another appreciated the possibility of “coming up with new ideas” and discussing them with colleagues. These responses suggest that the social and creative dimensions of the activity played an important motivational role.

Participants also enjoyed the more design-oriented aspects of the task. Some mentioned working on the visual form of the game, including colours and final details, while others valued developing the rules or imagining the game from the pupils’ point of view. Particularly interesting was the response of one participant who described the experience as “going back to the 9th grade” and remembering which kinds of tasks had once seemed easy and which had seemed impossible. This suggests that the design process encouraged some participants to think from the perspective of learners and to reflect on how mathematical content might be experienced by pupils.

However, the activity was not experienced as easy. The most demanding aspect was clearly the creation of questions and tasks. Several participants stated directly that the hardest part was inventing a sufficient number of tasks or designing the questions themselves. Others emphasized that this phase was not only cognitively demanding, but also time-consuming. In addition to task creation itself, participants mentioned the challenge of managing time, coordinating group work, and solving practical issues related to how the game should function.

One particularly rich response also referred to the use of AI during the design process. Although AI was used as a source of inspiration, the participant noted that many generated questions were too simple, leading, or incorrect, and therefore had to be substantially revised or discarded. This response suggests that even when technological support was available, participants still needed to engage critically with the material and adapt it carefully to educational purposes.

Importantly, the areas that participants found most challenging were closely connected to what they reported having learned during the process. Many respondents stated that they had learned how to create questions and tasks, including word problems, and how to formulate them clearly for pupils. One participant explicitly wrote that they had learned to “formulate questions so that they are understandable.” Others referred to learning teamwork, discussion, and the value of collective thinking. The participants reflected that although they had many ideas, it was difficult to find one that was realistically feasible, and that discussion with peers helped transform those ideas into an implementable concept. One participant summarized this insight in a concise but expressive way: “it is difficult and it takes more heads.”

These findings suggest that educational game design functioned not only as a creative task, but also as a learning experience that supported the development of practical pedagogical skills. The activity required participants to generate and refine content, formulate it in a comprehensible way, negotiate ideas with others, and make realistic design decisions. In this sense, what was most demanding in the process also became the most productive source of learning.

A thematic summary of the most frequently mentioned enjoyable, demanding, and learning-related aspects is presented in Table 3.

**Table 3: Main areas identified in participants' reflections**

| Area              | Main theme                          | Interpretation                                                   | Illustrative quote                                                   |
|-------------------|-------------------------------------|------------------------------------------------------------------|----------------------------------------------------------------------|
| Enjoyable aspects | Collaboration (6)                   | Working with peers was motivating and supportive                 | <i>"cooperation with the girls and inventing mathematical tasks"</i> |
|                   | Creativity and idea generation (10) | Participants valued inventing and discussing ideas               | <i>"coming up with new ideas"</i>                                    |
|                   | Design and learner perspective (4)  | Participants enjoyed rules, visuals, and thinking as pupils      | <i>"going back to the 9th grade"</i>                                 |
| Demanding aspects | Task and question creation (8)      | Creating enough suitable questions was the main challenge        | <i>"the most difficult part was creating the questions"</i>          |
|                   | Time and coordination (5)           | The process required planning and organization                   | <i>"to organize time and plan it so that we could manage it"</i>     |
|                   | Critical use of AI (2)              | AI helped with inspiration, but not with ready-to-use tasks      | <i>"too simple, leading, or completely incorrect"</i>                |
| Learning outcomes | Writing tasks and questions (6)     | Participants developed skills in constructing mathematical tasks | <i>"creating questions and tasks"</i>                                |
|                   | Clarity of formulation (8)          | They learned to phrase questions more clearly for pupils         | <i>"formulate questions so that they are understandable"</i>         |
|                   | Feasibility and teamwork (6)        | They learned to refine ideas collaboratively                     | <i>"it is difficult and it takes more heads"</i>                     |

### 3.3 Transforming Mathematical Content for Learners and Classroom use

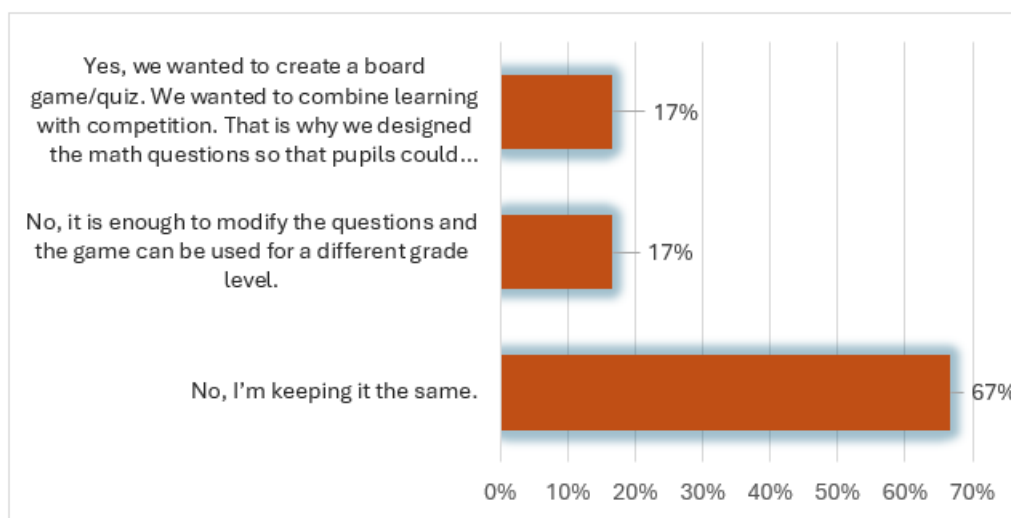
Another important theme concerned how participants approached the selection of the mathematical topic or game idea and how they thought about the content from the perspective of pupils. When explaining why they had chosen a particular topic, participants frequently referred to the fact that it seemed playful, engaging, useful, or close to pupils' needs. One participant wrote that the topic felt "playful, fun, but still educational," while another explained that it seemed "close to pupils." In some cases, the choice was also motivated by practical usefulness, for example in relation to preparation for lower secondary assessment or entrance examinations.

These answers indicate that the selection of the topic was not random. Rather, participants appeared to choose content they perceived as attractive, meaningful, and potentially useful in school practice. In some cases, they also considered broader applicability, for example by aiming to create a game that could be adapted for different grades or even include content from several school subjects.

This orientation towards pupils became even more visible in responses to the question about what had to be considered in order to make the mathematical content understandable and meaningful. Across the responses, participants repeatedly emphasized the need to think about the age, grade level, prior knowledge, and curricular background of the learners. One participant referred specifically to "what pupils already know in that grade and what they do not," while another pointed to the importance of how a question is worded, especially in the case of word problems.

Some responses also highlighted the need for adaptability. One participant noted that the teacher could create or modify questions for each topic area and thus adjust the level of difficulty according to pupils' age and grade. This suggests that participants were not only thinking about a fixed set of tasks, but also about the flexibility of the game as an instructional tool.

When asked whether the process of designing the game influenced their choice of mathematical content, most participants answered negatively. At the same time, some noted that although the content itself remained unchanged, the game could be adapted for other grade levels by modifying the questions. In most cases, they did not report changing the topic they had originally selected. At the same time, the responses indicate that the process could influence how the content was transformed into game form. In one case, for example, the group deliberately designed the questions so that pupils would be able to answer them within a short time limit in order to combine learning with competition in a quiz or board-game format. Thus, while the chosen mathematical topic often remained stable, the game format shaped the form and pace of the tasks. This pattern is also visible in the response distribution shown in Figure 1.



**Figure 1: Reported influence of game design on the choice of mathematical content**

Taken together, these findings suggest that participants were engaging in didactic thinking about content, learners, and instructional form. They did not only select mathematical topics; they also considered whether the content was appropriate for a specific group of pupils, whether it aligned with what pupils had already learned, and how it could be presented in a way that was both understandable and engaging. This indicates that designing educational games encouraged participants to reflect on the relationship between mathematical content and the needs of learners in school practice.

#### 4. Discussion and Conclusion

The findings suggest that designing an educational game was perceived by participants not only as an enjoyable activity, but also as a meaningful learning experience connected to their future role as mathematics teachers. Their reflections indicate that the activity combined creativity, collaboration, and instructional decision-making. In this sense, the results align with research showing that teachers need not only positive attitudes toward games, but also specific competences related to instructional design, organization, and pedagogical implementation of game-based learning (Chen et al., 2020).

An important result of this study is that participants described game design as a multi-stage process involving idea generation, concept refinement, decisions about mechanics and structure, division of responsibilities, content creation, and final design work. This corresponds well with literature, which presents game design as a structured and multidimensional process rather than a single moment of inspiration. Winn (2009), for example, argues that serious game design requires a formal design approach that brings together learning, gameplay, user experience, and technology, while Annetta (2010) similarly frames educational game design as a process that must balance multiple interconnected elements rather than simply “gamifying” content. Compared with these frameworks, the participants in the present study appear to have moved through several expected design stages, especially those related to concept formation, content creation, and game structure. At the same time, playtesting and iterative evaluation were not prominent in the participants’ reflections. Given that systematic testing was not a central aim of the assignment, this absence is not surprising. Nevertheless, it suggests a possible direction for extending similar activities, as further work with testing and

revision could offer additional insight into how pre-service teachers improve the balance between educational goals and gameplay (Winn, 2009).

A particularly strong finding concerns the relationship between what participants found most difficult and what they believed they learned most from. The hardest part of the process was clearly the creation of questions and tasks, yet this was also the area in which they most often reported learning. This suggests that the educational value of game design may lie precisely in the pedagogical challenges it creates. Question design can be understood as a form of professional learning in which participants had to transform mathematical content into tasks that were understandable, appropriately challenging, and suitable for gameplay. In this sense, their reflections point to an important aspect of mathematics teaching, as questioning is widely recognized as a central and demanding pedagogical skill (Aizikovitsh-Udi & Star, 2011; Moyer & Milewicz, 2002). The participants' repeated concern with wording, task difficulty, and age appropriateness therefore suggests that the design encouraged them to think not only about what mathematical content to include, but also about how to mediate that content for learners in a meaningful and accessible way.

The findings also point strongly to didactic thinking about learners. When explaining their choices, participants referred to pupils' age, grade level, prior knowledge, curriculum expectations, and the need to make the content understandable and meaningful. This suggests that the task did not remain on the level of creative production but encouraged reflection on the learner-content relationship. Such a result fits well with Chen et al.'s (2020) argument that game literacy for teachers includes not only familiarity with games, but also higher-level competences related to instructional alignment, pedagogical planning, and evaluation. In the present study, participants' repeated attention to what pupils "already know," whether tasks fit a given grade, and how questions should be phrased indicates that they were engaging with precisely these pedagogical concerns.

At the same time, the findings add an interesting nuance. For most participants, designing the game did not substantially change the mathematical topic they had originally selected. What changed more often was the form in which the content was presented. For example, in one case questions were adapted to fit a short, competitive quiz format. This suggests that the design process may not necessarily reshape what pre-service teachers want to teach, but it can reshape how they transform that content into an activity for learners. It indicates that the value of game design may lie less in curricular selection and more in pedagogical representation. This interpretation is compatible with serious game design frameworks, which stress the need to align learning goals with gameplay rather than merely placing content inside a game shell (Winn, 2009; Annetta, 2010).

The collaborative dimension of the findings is also noteworthy. Several participants emphasized discussion with peers, division of labour, and the importance of refining ideas together. One participant's statement that the task "takes more heads" captures the collective nature of the design process particularly well. This resonates with broader work on teacher preparation for game-based learning, which suggests that design competence does not emerge automatically and may benefit from shared reflection, pedagogical scaffolding, and explicit support (Chen et al., 2020). The collaborative aspect also seems especially relevant in light of the participants' difficulties with question design and feasibility, since peer discussion appeared to help them move from many possible ideas toward a workable instructional product.

Overall, the study supports the view that designing educational games can function as a valuable learning experience in pre-service mathematics teacher education. The activity appears to have engaged participants in thinking simultaneously about mathematical content, learners, questioning, game mechanics, and practical feasibility. Its value may therefore lie less in the final product alone and more in the reflective design work it requires. From this perspective, educational game design can be understood as a context in which pre-service teachers begin to connect pedagogical content knowledge with instructional design decisions. A practical implication is that such tasks may benefit from stronger scaffolding around question design, playtesting, and iterative revision, since these appear to be the areas where students both struggled most and learned most.

A limitation of the study is that the findings are based on self-reported reflections from an open-ended questionnaire. The data therefore capture participants' perceptions rather than direct observation of the design process or classroom use of the games. Some responses were also brief, which limited the depth of interpretation. The findings should be interpreted in light of the small sample size and possible self-selection bias due to the elective nature of the course. Future research could combine reflective data with analysis of the finished games, observations of the design process, or classroom implementation.

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**Ethics Declaration:** This study was conducted in accordance with the ethical guidelines for educational research. Participation was voluntary, and all participants were informed about the purpose of the research, their rights, and the procedures involved. Their responses were treated confidentially, stored securely, and used solely for research purposes in accordance with applicable data protection regulations.

**AI Declaration:** Artificial intelligence tools (specifically ChatGPT by OpenAI) were used to support the preparation of this paper. AI assistance was employed for improving language clarity and formalising style. All intellectual contributions, research design, data interpretation, and final decisions were made by the authors.

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