

Design Principles for a Digital Game to Address Mathematics Anxiety in the Classroom

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Abstract: Mathematics anxiety is increasingly recognized as a significant barrier to learning, affecting not only students' performance but also their motivation and long-term relationship with mathematics. Although digital game-based learning has shown potential to support motivation and learning in mathematics, only few games have been explicitly designed to prevent or alleviate mathematics anxiety. This study addresses that gap by examining how theory-informed design principles for an emotionally supportive digital mathematics game were implemented in the wireframe design of MathifyMe, a browser-based game for students aged 7-16. To investigate how these principles were translated into design features, we conducted walkthrough sessions with researchers, teachers, and students. The findings revealed that the design principles provided sufficient guidance for developing game features that stakeholders recognized as potentially helpful for supporting math-anxious learners. Several critical implementation issues were identified, and implications for the further design of the game are discussed. This paper contributes to research on digital games and mathematics anxiety by offering a theory-informed set of design principles for emotionally supportive mathematics game design.

Keywords: Mathematics anxiety, Game-based learning, Emotion-regulation, Digital games, Control value theory

1. Introduction

Mathematics anxiety (MA) is an important barrier to learning and participation. It is widely recognized as a distinct form of academic anxiety that can disrupt learning, logical reasoning, and decision-making in mathematical contexts (Ahmed et al., 2024; Kaushal et al., 2022). The relationship between MA and mathematical performance is complex and bidirectional: anxiety can impair performance, while repeated struggles with mathematics may in turn reinforce anxious feelings (Carey et al., 2016).

At the same time, a growing body of research suggests that digital game-based learning can enhance motivation, improve learning outcomes, and support personalized learning experiences that are often difficult to achieve through traditional instruction (Hussein et al., 2022; Hui et al., 2023). This makes digital games a potentially promising approach for addressing MA. Because MA includes emotional, cognitive, and motivational components, it is unlikely to be effectively reduced through simple content repetition or traditional frontal instruction alone (Carey et al., 2016). Instead, reducing MA requires integrated approaches that provide cognitive support, strengthen learners' sense of competence and control, foster emotional regulation, and promote more positive attitudes toward mathematics (Liu et al., 2025). In this regard, digital games offer a good alternative to create learning environments that are more supportive and engaging.

However, evidence for the effectiveness of digital games in reducing MA remains inconsistent (Dondio et al., 2023). One possible explanation is that many existing digital games were not specifically designed for learners with MA and often lack specific emotional support. As a result, the field still lacks clear guidance on how digital games can be intentionally designed to address the specific needs of math-anxious learners or to prevent MA in the classroom.

In a previous study the authors developed design principles based in the literature for the development of digital games for alleviating MA (Jukić Matić, Palha and Huhtasalo, 2025) which have been used to develop a prototype

digital mathematics learning game within the Erasmus+ project MathifyMe and intended to enhance emotional regulation during mathematical activities for students aged 7–16.

Against this background, this paper examines how theory-informed design principles for an emotionally supportive mathematics game were operationalized in the wireframe design of MathifyMe and how this alignment was perceived by key stakeholder groups. Rather than evaluating the game’s effectiveness, the study focuses on the early-stage translation of theoretical principles into concrete design features. This focus is particularly relevant, as emotionally supportive game design requires careful alignment between theoretical intentions and concrete gameplay elements already at the pre-prototype stage. The study is guided by the following research question: *How are the design principles that guide the development of a digital game aimed at addressing mathematics anxiety implemented in the wireframe design of the game?*

2. Background and Theoretical Framing

2.1 Mathematics Anxiety and Game-based Learning

MA refers to feelings of tension, worry, or fear that interfere with an individual’s ability to engage with and perform mathematical tasks (Beilock & Maloney, 2015). It can manifest emotionally (stress, nervousness), cognitively (negative self-beliefs, avoidance), and physiologically (increased heart rate, discomfort). MA affects students of all ages and can hinder both performance and motivation, leading to reduced confidence, lower achievement, and long-term disengagement from mathematics.

MA has been shown to have a situational and context-dependent nature (Pekrun, 2024). It can therefore be understood as a dynamic response that varies according to factors such as task difficulty, assessment conditions, and social context. Environmental factors, including negative teacher feedback, parental pressure, and performance-oriented instruction, have been identified as important triggers because they may heighten stress and reduce learners’ sense of control (Kaushal et al., 2022; Huhtasalo et al., 2025). This situational perspective is particularly relevant to the present study, as it suggests that MA is shaped not only by individual predispositions but also by the design of learning environments and task experiences.

Digital-game environments may be especially suited to reducing fear of failure and supporting persistence because they can frame mathematical activity as enjoyable, less formal, and immersive (Hussein et al, 2022; Hiu et al, 2023), thereby fostering self-confidence and more positive attitudes toward mathematics. Moreover, Dondio et al. (2023) show that reductions in MA are more likely when gameplay includes collaborative and social interaction and when interventions are sustained over time, suggesting that supportive peer interaction, intrinsic motivation, and adaptive game features may help interrupt the cycle in which anxiety undermines performance and performance, in turn, reinforces anxiety.

2.2 Control-value Theory

Control-Value Theory (CVT) explains achievement emotions as arising from two central appraisals: perceived control and perceived value (Pekrun, 2024). Perceived control refers to learners’ beliefs about their capacity to influence success, manage task demands, and cope effectively with learning activities. Perceived value refers to the subjective importance, usefulness, interest, or cost attached to an activity or its outcomes. Within CVT, different configurations of control and value give rise to different emotions: high control and positive value support enjoyment, low control combined with high value promotes anxiety, low value contributes to boredom, and perceived uncontrollable failure may lead to hopelessness. Emotions thus arise not from tasks themselves, but from learners’ appraisals of their manageability and significance.

These appraisals are domain-specific, meaning that MA should be understood as an emotion tied specifically to mathematics rather than as a generalized school-related emotion (Broda et al., 2023). In this domain, MA is most likely to emerge when students perceive mathematics as important but experience low control over their performance (Broda et al., 2023; Pekrun, 2024). This anxiety can impair concentration, working memory, persistence, and confidence, thereby contributing to a negative cycle of diminished performance and heightened emotional distress.

Loderer et al. (2020) argue that emotionally supportive environments should strengthen students’ sense of control while fostering positive task value. This includes aligning task difficulty with learner competence, ensuring clarity of task structure, and providing scaffolding through hints, explanations, or adaptive support. The authors also emphasize the importance of mastery-oriented feedback, messages that reinforce the controllability of learning and the value of effort, and reward systems that do not overemphasize failure. In addition, supportive narrative elements, appealing audiovisual design, opportunities for autonomy and choice,

and cooperative rather than overly competitive structures may help reduce anxiety while promoting enjoyment and curiosity.

Concluding, these perspectives suggest that MA is not only an individual position but also a context-sensitive emotional experience that may be shaped through design. This provides a theoretical basis for formulating design principles for digital games intended to support learners experiencing MA.

3. Design Principles for the Development of a Digital Game on MA

DP1: Safe environment for errors emphasizes mistakes as a routine and productive part of learning. Learners' perception of control is strengthened when errors are separated from stress and negative evaluation (Pekrun, 2024). Learners should be encouraged to interpret mistakes as opportunities for competence development and self-regulation rather than as signs of inability. To support this, punitive consequences such as the loss of points or lives should be avoided, since such mechanics may amplify fear of failure and perceived threat (Dondio et al., 2023). Instead, errors should trigger constructive feedback, opportunities for retrying tasks, and invitations to explore alternative strategies.

DP2: Adaptive challenge and feedback refer to the design of game experiences in which task complexity is adjusted so that it remains challenging but attainable for the learner. This principle is linked to students' perceived competence and sense of influence over the outcome of an activity (Pekrun, 2024). When this adaptive structure is combined with feedback that corrects errors constructively while also affirming learners' progress and effort, learners are more likely to build confidence in their mathematical abilities, strengthening their self-efficacy (Demedts et al., 2024; Liu et al., 2025).

DP3: Emotional regulation tools and reflection are included as a principle to help learners understand and manage their emotional responses during mathematical activity. The literature (e.g. Pekrun, 2024) suggests that regular opportunities for reflection and emotional support can increase students' sense of agency over their affective experiences and reinforce the value of effort and persistence. In design terms, this may involve features such as emotion check-ins, supportive messages after failure, or brief stress-management activities embedded within gameplay. Such tools can help learners identify their emotional state, normalize feelings of anxiety, and practice strategies for coping with stress.

DP4: Mastery-oriented and low-stakes practice emphasize gradual skill development, repeated opportunities for success, and low-pressure engagement with mathematical content, enabling learners to build competence incrementally and strengthen their sense of control over mathematical tasks. Because learners with MA may underestimate their own abilities and avoid challenges, the game environment should emphasize improvement, persistence, and intrinsic motivation rather than performance comparison. The literature (e.g. Dondio et al., 2023) also highlights the importance of sustained duration and repeated practice, suggesting that longer and more iterative interventions may further strengthen perceptions of mastery and control.

DP5: Immersive narrative and meaningful context aim to increase the subjective value of mathematical activity by embedding it in engaging and personally relevant situations. By integrating mathematical tasks into stories, missions, or applied scenarios, games can make the activity feel more worthwhile and emotionally engaging (Dondio et al., 2023). Meaningful narrative integration may indirectly reduce MA by increasing both task value and emotional relevance, especially for learners who would otherwise perceive mathematics as meaningless or intimidating (Balt et al., 2022).

DP6: Collaborative play and social support emphasize that, through collaboration and social support, mathematical activity can become associated with a sense of belonging, and shared achievement. These experiences may enhance learners' enjoyment, intrinsic motivation, and willingness to engage with mathematical tasks (Dondio et al., 2023; Balt et al., 2022). At the same time, working with peers offers opportunities for strategy modelling and knowledge sharing, allowing learners to observe how others approach and overcome difficulties. This process can reinforce self-efficacy by showing that success is achievable through effort and strategic thinking. Collaborative play also creates space for emotional regulation, as learners can communicate frustrations, encourage one another, and receive mutual support.

DP7: Non-competitive and non-comparative progress tracking seeks to minimize the pressure associated with social comparison and performance evaluation. When students are encouraged to focus on personal growth rather than outperforming others, they are more likely to experience control, take pride in their own progress, and feel less anxious about being judged (Pekrun, 2024; Liu et al., 2025). The literature (e.g. Dondio et al., 2023) recommends avoiding mechanics such as public leaderboards, high-stakes rankings, or peer-to-peer score

comparisons, as these may reduce enjoyment and increase tension for learners with MA. Instead, games should allow students to monitor their own improvement over time and reward personal milestones through supportive indicators.

4. The MathifyMe Digital Game Prototype

4.1 Game Description

MathifyMe is a browser-based digital mathematics learning game for students aged 7–16, designed to support emotional regulation during mathematical activity. AUAS researchers designed the game specifications; Game Tailors handled technical development, with project partners and teachers contributing throughout. The present study focuses on 5th–7th grade (10–14 years old students). In addition to mathematics learning, the game includes features intended to help students manage frustration, anxiety, and other negative emotions that may arise during problem-solving. The system consists of three main components: the game space, where students complete mathematical tasks in a point-and-click environment with embedded emotional support options; the teacher portal, where teachers can assign and customize activities; and the learning analytics dashboard, which provides insight into students' progress and emotional patterns. The game can be used both in the classroom and for homework.

4.2 Examples of how Specific Principles are Reflected in the Prototype

The game is structured around an overarching narrative in which students enter a mathematics park where different attractions need to be tested, repaired, or rebuilt. Each attraction is linked to mathematical topics and practices, such as ordering, comparing, and problem solving. This narrative design reflects the principle of **immersive narrative and meaningful context (DP5)**, as mathematical tasks are embedded in purposeful situations within the game world. By situating mathematics within playful and meaningful challenges, the game aims to strengthen students' perceived task value.

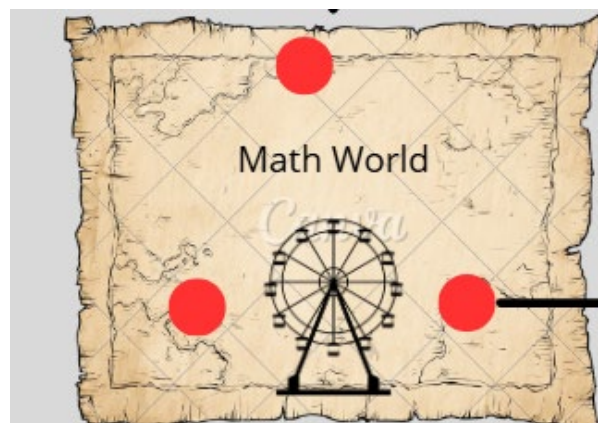


Figure 1: Schematic map of the math park in the wireframe. In the full game version, the map will be presented in color and will include multiple park attractions. The areas currently marked with red dots indicate attractions or park locations that will be highlighted as interactive for the player

After the introductory story, students access a park map (Figure 1) showing the available attractions and activities selected by the teacher through the teacher portal. The map supports the principle **mastery-oriented, low-stakes practice (DP4)** by offering students a clear overview of available tasks and allowing them to choose activities they feel ready to complete. This supports self-paced progression, gradual challenge, and a sense of control. During problem solving, the game provides immediate visual feedback, such as a movement, a colour or other visual artifact in response to students' input. This direct connection between action and outcome focused to help students interpret their choices and revise their thinking reflects the principle of **adaptive challenge and feedback (DP2)**. Completed tasks are highlighted on the map, further reinforcing progress and accomplishment. Also according the same principle, the game monitors students' attempts and, when needed, suggests an easier task or a short break.

Within each task environment, students can activate several supportive tools at any point during problem solving (Figure 2). These include the skill bar, an NPC that provides hints or companionship (Hint), a pause reward offering a brief non-mathematical mini-game for relaxation (Break/mini-games), and a control mode that gives students access to a safe playground for experimentation and learning from errors. Together, these features

operationalize the principles of **emotional regulation tools and reflection (DP3)** and **safe environment for learning from errors (DP1)**.

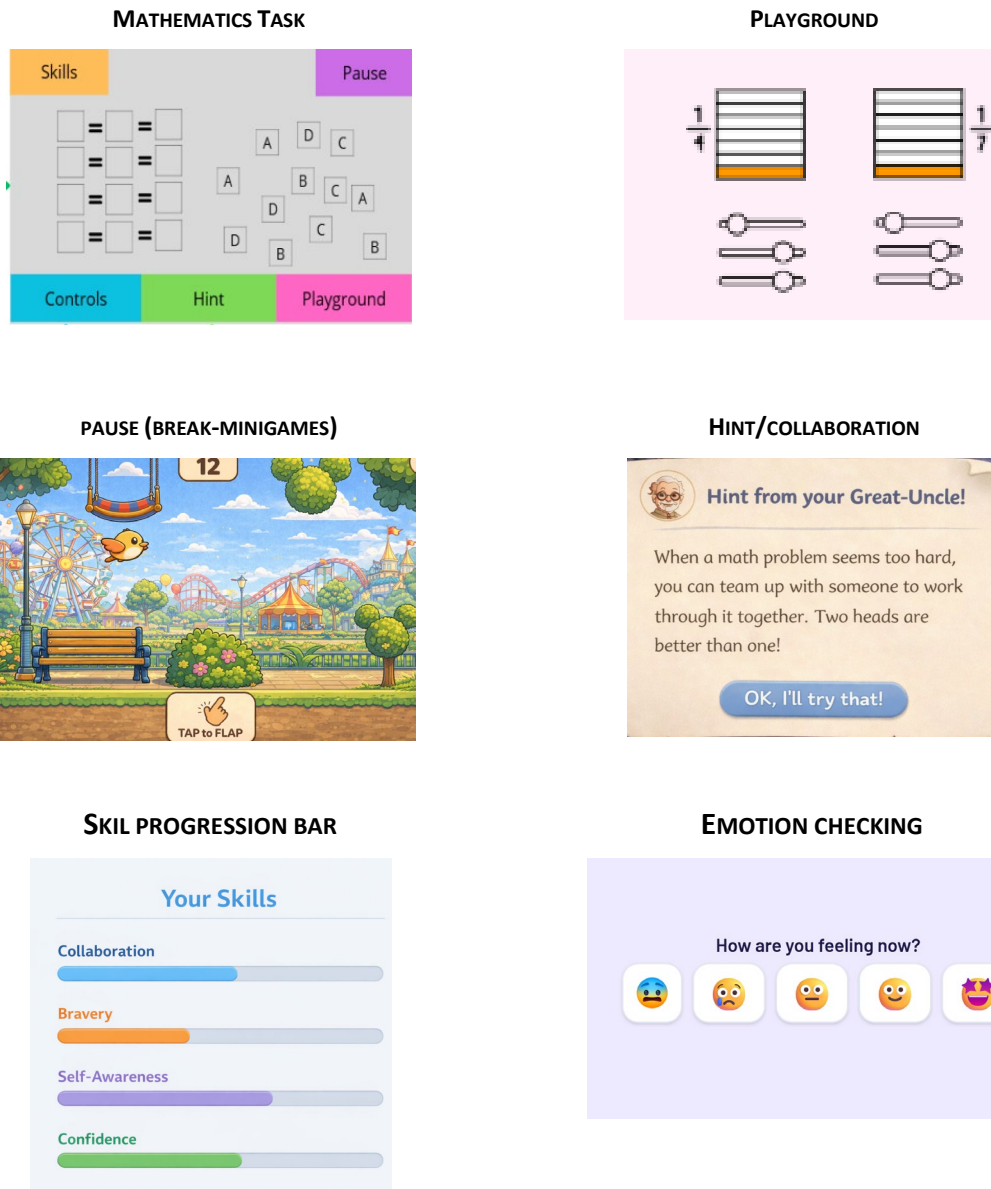


Figure 2: Game features in the Wireframe design

Student progress is represented through a skill bar informed by the principle of **non-competitive and non-comparative progress (DP7)**. The skill bar visualizes how students respond to challenges and develop their own learning strategies. It rewards processes that may strengthen perceived control and task value, while keeping the underlying point system invisible to avoid unnecessary pressure. To prevent information overload, the system focuses on four skills relevant to emotional regulation in mathematics learning: *confidence*, *bravery*, *collaboration*, and *self-awareness*. Confidence-growth is supported when students choose manageable tasks or return to practise earlier content. Bravery-growth reflects students' attempt to solve unfamiliar tasks, retry after mistakes, or engage in "detective tasks" that require them to identify and understand errors. Collaboration is promoted by rewarding help-seeking from peer-students and non-player characters, reframing assistance as a productive learning strategy rather than a sign of incompetence. Self-awareness is supported through mechanisms that encourage students to take breaks, reflect on emotions, and communicate how they feel, for example by collecting and using emojis during gameplay. In addition the game will also encourage **collaborative play and social support (DP6)** through prompting messages to students for sharing strategies, looking for and offering help to peers.

5. Methodology

This study adopted a qualitative exploratory design to examine how design principles aimed at alleviating mathematics anxiety can be translated into a digital game prototype. This approach was appropriate because limited empirically grounded guidance is available on this design problem. Walkthrough sessions were used as the main method to examine the alignment between the design principles and the prototype. This method enabled a systematic analysis of how specific design elements were experienced and interpreted in relation to the intended emotional and motivational goals. It also helped identify omissions and opportunities for improvement in the design.

The walkthrough sessions involved five participants from the partner countries of the MathifyMe project (two researchers in mathematics education and three teachers), and one 14-old student. These stakeholders took part in individual or collective interview, enabling the study to bring together complementary perspectives from educational research, classroom implementation, and end-user experience. In total there were three walkthrough sessions, and the data were collected through these sessions. Each session began with an introduction to the MathifyMe project, the project definition of MA, and its grounding in Control-Value Theory. The seven design principles were then briefly introduced. Participants were subsequently guided through the main parts of the wireframe and, for each part, were asked whether and how they recognized the design principles. The sessions also remained open for participants to raise additional questions, concerns, or relevant issues.

The data were analysed using a qualitative exploratory approach, consistent with the study design. The seven design principles served as analytical categories to examine how participants perceived their presence across the wireframe. First, the researchers analysed participants' comments on each wireframe feature and categorised the alignment between each design principle and its implementation as strong, moderate, or weak. The results are presented in Table 1. Second, the researchers compared participants' responses across wireframe features to identify common themes and implementation issues, which are described in Section 6.2.

6. Findings

6.1 Alignment Between Prototype Features and Design Principles

Features that stakeholders viewed as successfully reflecting the design principles included the math-park narrative, the mathematical tasks, the break/mini-game, and the emotion-checking features. Other features, such as the main map, the control slider, and the skill bar, were seen as partially reflecting the design principles. The Playground and the help-seeking/collaboration features were considered underdeveloped. Table 1 provides an overview of the extent to which stakeholders perceived each feature as reflecting the design principles.

Table 1: Overview stakeholders' perceptions of the design principles

Game-design feature	Student	Teachers	Researchers	Related design principle(s)
Math-park narrative	strong	strong	weak	DP4, DP5
Main map	strong	moderate	weak	DP5, DP7
Mathematical task	strong	strong	strong	DP1, DP2, DP4
Break / mini-game	strong	strong	strong	DP3
Playground	unclear	moderate	unclear	DP3
Help-seeking / collaboration	weak	weak	strong	DP3, DP6
Control Slide	moderate	strong	unclear	DP2, DP3, DP4
Skill bar Slide	moderate	strong	unclear	DP7
Emotion	strong	strong	weak	DP3

6.2 Critical Implementation Challenges

In addition to examining the alignment between the game features and the design principles, we used thematic analysis to identify critical implementation issues. Four main themes emerged from the stakeholder interviews:

Integration of emotional regulation within mathematics tasks and game flow

Stakeholders recognized the principles related to a safe environment for errors (DP1), adaptive difficulty and feedback (DP2), emotional regulation (DP3), and mastery-oriented, low-stakes practice (DP4). However, these principles were not yet sufficiently visible in the game flow. They were uncertain how the emotion-regulation features (breaks, the playground, the control slider, and hints/collaboration) would work in practice, including how long students could use them, how they would return to the main activity, and how these features would remain connected to meaningful mathematics learning.

Stakeholders also questioned student and teacher agency, including which options would be predefined by the game and how these would relate to teacher support. Another unresolved issue was how the system would respond when students repeatedly get stuck or make errors, as this was not yet included in the wireframe.

Finally, while mastery-oriented, low-stakes practice (DP4) was visible in the mathematical tasks, it remained unclear how task complexity would increase over time and how the design would support students' sense of success. Teachers also questioned whether the control option would be intuitive for students and whether it would add support beyond what teachers already provide.

Measuring in-game emotions

Stakeholders questioned whether the proposed emoticons were sufficient to capture students' emotions, noting that emotions such as anger and frustration were missing and that some icons could be ambiguous. They suggested adding labels, including additional emotions such as anger, frustration, or indifference, or allowing students to draw how they feel. They also questioned how the system would use these emotion measurements, particularly how it would respond to signs of frustration, anger, boredom, or fear and how these signals would shape the game flow or support offered.

Visualizing individual progress growth

Non-comparative progress tracking (DP7) was mainly recognized in the skill bar, which stakeholders saw as a promising way to represent personal growth without comparison to others. However, they questioned whether it would be clear and motivating for students. In particular, the current design did not clearly distinguish between progress based on genuine effort and achievement and progress based on mere participation.

Stakeholders also noted that the wireframe did not explain how skills such as self-confidence, self-awareness, or courage would be operationalized and measured. The student suggested using clearer visual cues, such as colour changes, while a teacher recommended adding verbal feedback that acknowledges progress relative to the student's own starting point. Finally, stakeholders questioned where and how the skill bar would be accessed during gameplay.

Integration of the story and collaboration and social support within the game.

Immersive narrative and meaningful context (DP5) were mainly recognized in the introductory math-park storyline. Although stakeholders found the narrative potentially engaging, they stressed that it should be more clearly connected to the mathematical tasks and game features. Otherwise, the story risks remaining only an external frame rather than a meaningful context for restoring the park. Schoenherr et al (2025) highlight the importance of cultivating students' appreciation of the value of mathematics learning, including in areas where they experience difficulty, for sustaining curiosity and motivation in mathematics. This aspect is underdeveloped in the narrative and mathematical tasks. It should be also explicitly included in DP5.

Collaborative and social support components (DP6) were largely missing. The student described the current design as "too solo," and teachers emphasized that system-based help does not constitute real collaboration because it lacks joint work, shared problem-solving, or a common goal.

7. Discussion and Further Research

7.1 Contributions to the Field

How digital games can be intentionally designed to address the needs of math-anxious learners, or to prevent mathematics anxiety in the classroom, remains an open question. This study presents a set of design principles and game features intended to guide the integration of emotion regulation, mathematical learning, and gameplay. It also investigates how these principles are implemented in the wireframe of the digital game MathifyMe. Because there is still limited knowledge on how theoretical principles and research findings can be translated into concrete game features, the proposed set of design principles represents a distinct contribution to game-based learning research.

A first main finding is that the design principles provided sufficient guidance for developing game features that stakeholders recognized as potentially helpful for supporting math-anxious learners. Although several critical implementation issues were identified, stakeholders did not reject any of the proposed features as inappropriate. Most concerns related instead to the integration of these features within the overall game flow.

A second main finding concerns the refinement of the design principles:

- The principle on emotional regulation tools and reflection (DP3) should include clearer guidance on emotion measurement, which was largely absent from the original description.
- The principles on immersive narrative and meaningful context (DP5), as well as collaboration and social support (DP6), should provide more specific guidance on how these elements can be integrated throughout the game flow. This is particularly relevant in relation to emotion-regulation features and the cultivation of students' appreciation of the value of mathematics (Schoenherr et al., 2025). Moreover, research highlights collaborative and peer-supported structures as components of effective interventions for reducing anxiety (Dondio et al., 2023). The principle on non-comparative progress tracking (DP7) should be more explicitly connected to student motivation and agency, as visualizing personal growth does not automatically create a sense of progress or success. Feedback messages may strengthen this principle by helping students interpret their progress in a mastery-oriented way. This suggestion aligns with Loderer et al. (2020), who emphasize the importance of mastery-oriented feedback, messages that reinforce the controllability of learning and the value of effort.

These findings highlight the importance of future iterative development and testing, especially in settings that allow for a more dynamic analysis of game flow, player interaction, and system responses.

7.2 Limitations and Further Research

This study has several limitations. One limitation concerns the use of a wireframe as the research instrument. The wireframe was useful for presenting and discussing the intended game features, but its static nature limited the extent to which emotionally supportive features could be tested. Emotional support is inherently situational (Pekrun, 2024). It becomes meaningful when it responds to learners' experiences, difficulties, or emotional states at relevant moments during gameplay.

A related issue concerns the different perspectives of the intended users. The game is designed for classroom use, with both teachers and students as primary users, but with different roles and interests. Teachers may primarily use the game as a pedagogical resource, whereas students may engage with it mainly as a playful experience. The design aims to balance these perspectives, with game developers translating pedagogical and mathematical requirements into intrinsically integrated game mechanics and narrative elements. Nevertheless, tensions may remain between teachers' pedagogical intentions, students' preferences as players, and developers' design considerations. This balance warrants further investigation in classroom-based research.

Another limitation concerns the small number of participants. While this was suitable for the exploratory character of the study, it limited the range and diversity of feedback obtained.

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AI Declaration: ChatGPT was used selectively for editing, as the authors are not native English speakers, and to refine the style, clarity, and readability of the paper sections. All final content was critically reviewed and revised by the authors.

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