Needs Analysis to Define a Digital Learning Game Aimed at Coping with Mathematics Anxiety

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Abstract: Mathematics anxiety is a well-documented phenomenon affecting students' learning experiences, engagement, and long-term career choices. This research is part of a wider effort to mitigate and prevent mathematics anxiety through the development of a digital learning game, supported by a follow-up teacher professional development programme. Previous research highlights a critical gap in the availability of games specifically designed to mitigate mathematics anxiety and promote learning and emotional well-being. This paper focuses on the needs analysis phase of a game development process. The research follows the design-based approach, in which the first step involves identifying needs and defining educational objectives. The needs analysis is designed on a multinational basis by an interdisciplinary research team from five European countries. It aims to identify the requirements of teachers and students for the digital learning game based on a literature review, an analysis of mathematics curricula in the five European countries, as well as surveys conducted among teachers, students, and parents. Focus group interviews in these five countries deepen the understanding of teachers' needs and perspectives. Results from the analysis will guide the design stage and contribute to the creation of game mechanics that align with the learning goals. Later, the game will be iteratively built, tested and improved together with teachers and students. The needs analysis and definition of game requirements are carried out by a multidisciplinary team using co-design methods. The team includes experts from the fields of mathematics, game development, pedagogy, mental health and co-design. In addition to developing a digital learning game, the game is particularly aimed at supporting emotional well-being and engagement of the player in order to mitigate anxiety related to learning maths. Preliminary results from needs analysis reveal that specific game mechanics, modular design, and a positive psychology approach are considered essential in supporting student´s learning and well- being. The results form the basis for the further game design.

Keywords: Mathematics anxiety, Game-Based learning, Needs analysis, Digital learning tools, Digital learning games, Teacher professional development

1. Introduction: Understanding Mathematics Anxiety: Causes, Consequences and Interventions

Mathematics anxiety (MA) is widely recognized as a distinct form of academic anxiety that disrupts learning, logical reasoning, and decision-making in mathematical contexts (Ahmmed et al., 2024; Kaushal et al., 2022). Building on this understanding, it is noteworthy that although MA has been conceptualized from educational, psychological, and clinical perspectives, it consistently affects both low- and high-achieving students. It often emerges early, triggered by negative classroom experiences, high-stakes assessments, or unsupportive teaching practices (Rada & Lucietto, 2022). The relationship between MA and mathematical performance is complex and bidirectional: anxiety can impair performance, while repeated struggles may reinforce anxious feelings (Carey et al., 2016). Recent studies estimate that approximately one in six students experiences moderate to high levels of MA, with symptoms often emerging already in primary school (Hill et al., 2016).

Furthermore, gender differences are consistently reported, with girls experiencing higher levels of anxiety despite performing similarly to boys, contributing to persistent gender gaps in STEM (Science, Technology, Engineering and Mathematics) engagement and careers (Levy et al., 2021; Stoel et al., 2016). If left unaddressed, MA can lead to a self-perpetuating cycle of avoidance, underachievement, and reduced future opportunities, even among capable students.

Given the well-documented impact of MA, game-based learning (GBL) – particularly digital GBL – has gained attention for improving student engagement, motivation, and confidence in mathematics (Barz et al., 2023; Cole et al., 2023). Serious educational games offer interactive and accessible ways to explore mathematical concepts (Hwa, 2018), and previous studies show their potential to enhance learning outcomes and foster positive attitudes toward mathematics (Vanbecelaere et al., 2020; Moyer-Packenham et al., 2023). However, it is essential to recognize that a recent meta-analysis (Dondio et al., 2023) revealed that while non-digital games can moderately reduce MA, digital games have had only a negligible impact, possibly due to the lack of games specifically targeting anxiety as well as the dominance of single-player designs. A study on the digital game *Seven Spells* (Almo and Amaral, 2024) showed that competition against human players intensified MA effects, emphasizing the need for careful consideration of game mechanics and social dynamics when designing games for emotionally vulnerable learners.

This paper is part of a broader European research initiative involving Finland, the Netherlands, Croatia, Malta, and Portugal, aimed at developing a digital learning game and a related teacher professional development programme to help reduce MA among 5–16-year-old students. Following a design-based research (DBR) approach, the work begins with a design of comprehensive needs analysis to identify learner needs and contextual factors. The co-designed game will draw on expertise in education, mental health, game development, and co-design, with goals extending beyond cognitive improvement to fostering emotional well-being, resilience, and long-term positive engagement with mathematics.

This article is structured as follows. It presents the needs analysis that serves as the foundation for the development of both a digital learning game and a teacher professional development programme. The needs analysis consists of four interrelated components: (1) a review of existing literature on MA and digital learning game development (2) a comparative curriculum analysis across five European countries, (3) electronic questionnaires (eQuestionnaires) targeted at teachers, students, and parents, and (4) focus group interviews with teachers. As the research is still ongoing, this article focuses on the needs analysis and its methodology and design. The findings presented are preliminary and provide an initial overview of emerging themes and user needs. The article concludes with key insights and outlines future steps in the development process.

2. Methodology

The needs analysis in this research included several components: a literature review, a comparative analysis of mathematics curricula, eQuestionnaires for teachers, students, and parents, and focus group interviews with teachers (Figure 1). The integration of findings from these components enables a comprehensive understanding of mathematics anxiety and the specific needs of both learners and educators. This multi-layered methodological approach not only elucidates the challenges inherent in mathematics learning but also provides a robust foundation for the design of a targeted digital learning game. Additionally, the insights generated will inform the development of a teacher professional development program that aligns with empirically identified needs and pedagogical objectives.

To establish a solid theoretical foundation, the literature review was conducted using international peer-reviewed research literature, in English, published between 2015 and 2025 – including studies on mathematics anxiety and existing educational games designed to reduce it. The review focused on identifying the key causes and contributing factors of mathematics anxiety, its cognitive and academic consequences, and relevant game-based intervention strategies.

In the curriculum analysis the structure and flexibility of mathematics education were compared across five participating European countries with particular focus on curriculum detail, teaching methods, integration of innovation, and considerations for MA. This comparison highlighted critical differences and similarities, informing the game design and professional development strategies.

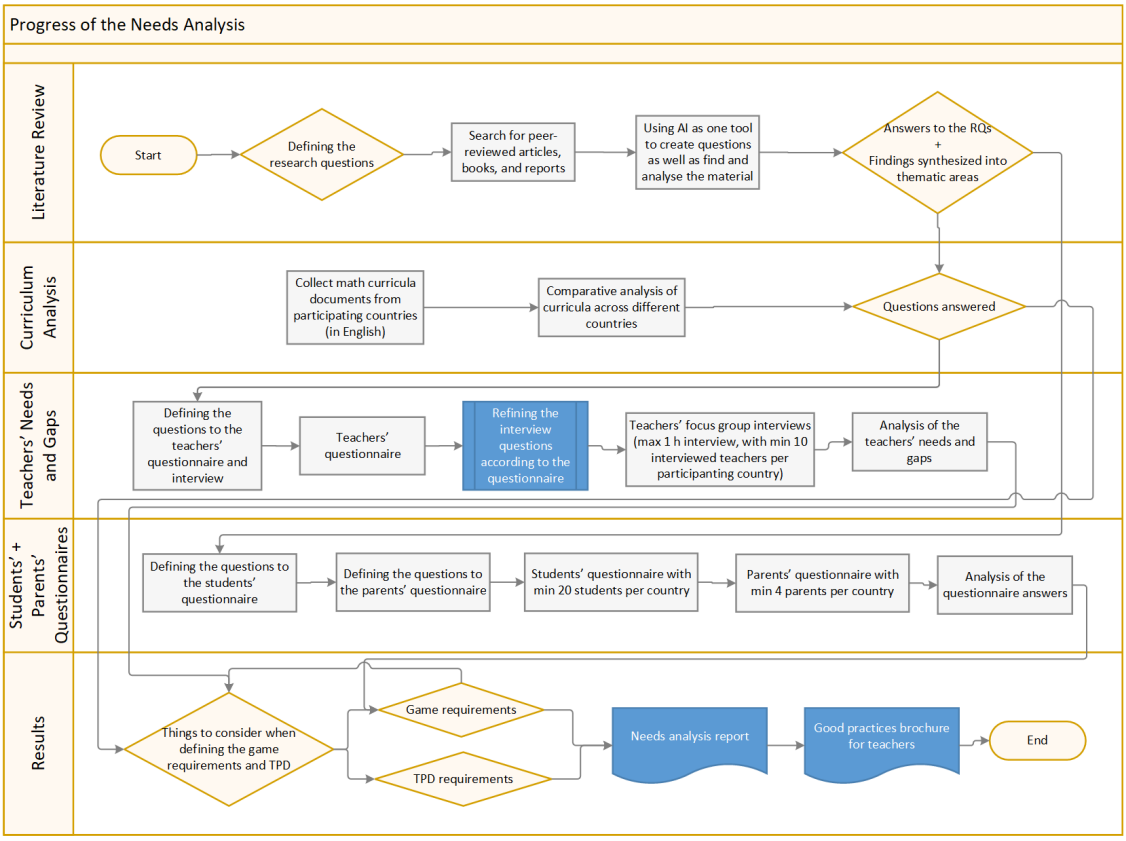

Figure 1: Progress of the needs analysis

To gain insights from various perspectives, teachers', students' and parents' perspectives on maths anxiety and good practices for mitigating and coping with it were identified through eQuestionnaires. Separate eQuestionnaires were designed and implemented for each group of respondents. The main objective of the teachers' eQuestionnaire was to find answers on the extent to which teachers identify maths anxiety, what tools they have to mitigate maths anxiety and help students with MA, and what kind of digital game they would like to have available for this purpose. Following participation in the eQuestionnaire, the teachers had the possibility to register in focus group interviews, which deepened our understanding of teachers' needs and knowledge gaps.

In parallel, the students' eQuestionnaire explored their feelings during maths tasks and lessons, their coping strategies, and their interest in learning through games. Questions differed between elementary and middle school students, with older students expected to provide more reflective responses. The questionnaire for 4th–6th graders was slightly more detailed than for 1st–3rd graders. The term "mathematics anxiety" was not used; instead, students were encouraged to describe their experiences and coping methods. Complementing these insights, the parents' questionnaire – the most concise of the three – focused on their perceptions of their children's maths anxiety, the school's mitigation efforts, and their satisfaction with these approaches. Together, these components provide a comprehensive view of the experiences and expectations related to MA across different stakeholders.

3. Key Outcomes of the Needs Analysis

3.1 Causes and Contributing Factors

The literature review, which included 39 peer-reviewed articles, highlights several emerging themes related to multiple factors contributing to MA, often categorized in personal, psychological, cognitive, and environmental domains (Kaushal et al., 2022; Mammarella et al., 2023). Among personal traits, gender is frequently discussed: although female students often perform equally well in mathematics, they tend to report higher levels of anxiety, possibly due to internalized societal stereotypes (Szűcs & Toffalini, 2023; Hadley, 2025).

Self-efficacy, or belief in one's ability to succeed in math, is a major psychological predictor of MA. Lower self-efficacy is strongly correlated with higher anxiety and poorer performance (Rozgonjuk et al., 2020; Khasawneh

et al., 2021). Other internal factors include perfectionism, general anxiety, and low confidence. Externally, negative teacher feedback, parental pressure, rigid instruction, and performance-focused assessments increase stress and reduce perceived control, further fuelling MA (Ahmmed et al., 2024; Rada & Lucietto, 2022). Recent studies have also revealed that genetic factors may play a role in MA development. For instance, Malanchini et al., (2020) found that up to 75 % of the variance in MA could be explained by genetic links to attitudes and abilities in math, while Wang et al. reported a 40 % heritable component (as cited in Ahmmed et al., 2024).

3.2 Cognitive Mechanisms and Academic Consequences

At the cognitive level, MA interferes with working memory, which is essential for holding and manipulating numerical information. As a result, anxious students often struggle to concentrate, switch strategies, or solve multi-step problems due to cognitive overload (Jiang et al., 2021; Justicia-Galiano et al., 2016). This inflexible persistence can trap students in inefficient problem-solving loops (Ramirez et al., 2016), undermining their ability to improve or adapt.

MA is consistently linked with reduced math performance, lower academic motivation, and negative attitudes toward mathematics (Mammarella et al., 2023; Khasawneh et al., 2021). Students with high MA tend to avoid math-related courses and careers, contributing to a long-term skills gap in STEM fields (Kaushal et al., 2022; Rada & Lucietto, 2022). Over time, this avoidance may lead to decreased confidence, school disengagement, and reduced socioeconomic opportunities.

3.3 Intervention Strategies

Because MA is multi-causal, its effective management requires multi-layered interventions. Promoting a growth mindset, where students see mistakes as learning opportunities, has shown positive effects in reducing anxiety and increasing resilience (Mammarella et al., 2023). Additionally, enhancing self-efficacy through positive reinforcement, step-by-step scaffolding, and real-world applications helps students regain confidence and motivation (Rozgonjuk et al., 2020; Khasawneh et al., 2021). Cognitive-behavioral strategies such as expressive writing, mindfulness, and relaxation techniques help students regulate anxiety before assessments (Beilock & Maloney, 2015; Ramirez et al., 2016). Meanwhile, instructional approaches that emphasize conceptual understanding, reduce time pressure, and offer varied assessment formats (e.g., projects, portfolios) can reduce classroom-based stressors (Hadley, 2025; Rada & Lucietto, 2022). Finally, the role of teachers and parents is crucial. Educators should foster a safe learning environment where effort is valued over speed or correctness, and parents should avoid negative math talk and focus on constructive support (Ahmmed et al., 2024; Kaushal et al., 2022).

Building on these insights and based on the reviewed literature, we define mathematics anxiety as an emotional reaction characterized by feelings of fear, tension, and apprehension when engaging with mathematical tasks or situations. It involves cognitive, emotional, physiological, and behavioural responses that can impair mathematical performance, lead to avoidance of math-related activities, and affect academic and career trajectories, even among individuals with sufficient math skills.

3.4 Game-Based Learning (GBL) and Emotional Regulation

Findings on the different effects of digital and non-digital games highlight the importance of purposefully designed learning games that support both cognitive development and the emotional well-being of math-anxious students. Drawing from these insights, effective elements from non-digital games, such as scaffolding, adaptability, and positive feedback, will be incorporated into the mechanics and progression of the digital game currently under development.

Digital games offer opportunities for iterative learning without the fear of failure, helping students build resilience and a more positive attitude toward mathematics (Chen et al., 2021). Incorporating principles of positive psychology—such as encouragement, goal orientation, and autonomy—can enhance learners' self-confidence and reduce mathematics anxiety (Almo et al., 2024).

Key game design features identified in the literature include scaffolding, adaptive difficulty, narrative and storytelling elements, personalized feedback, and emotional regulation support. These mechanisms allow learners to progress at their own pace, stay motivated, and develop a sense of control (Bilgin, 2021; Abbacan et al., 2025). Gamification elements like points, badges and evolving game characters can further boost engagement when integrated thoughtfully within a strong pedagogical framework (Jutin & Maat, 2024; Alt, 2023). The promising design principles, mechanics, and their expected outcomes identified from the literature review are illustrated in Figure 2.

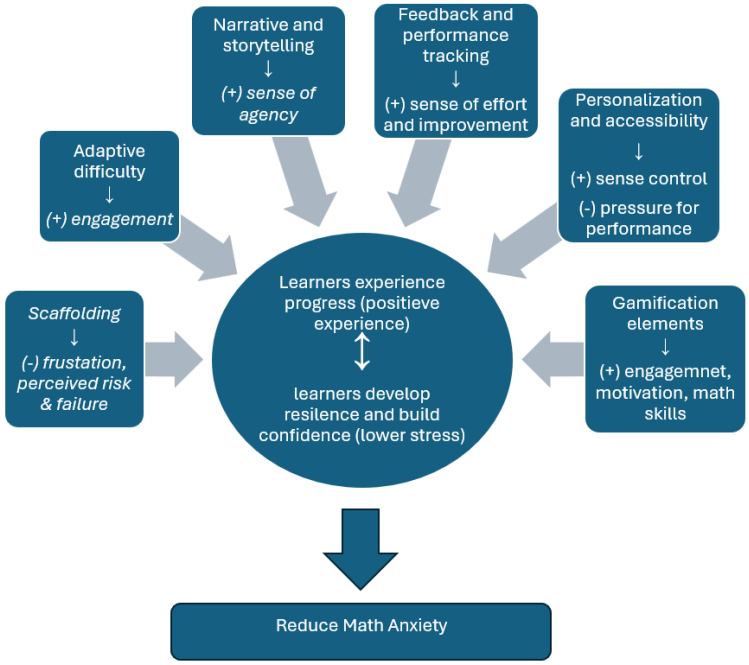

Figure 2: Design principles and game mechanics

To conclude, mathematics anxiety is shaped by a wide range of factors and has far-reaching effects on academic paths and well-being of learners. Educational games have the potential to play a meaningful role – both now and in the future – in supporting learning, emotional regulation, and overall student well-being.

3.5 Curriculum Analysis

The curriculum analysis used the mathematics curricula of all five countries (TIMSS 2015 Encyclopedia, 2015), which the researchers analysed from the perspective of the literature review and the research objectives. Table 1 presents the results of the curriculum analysis are presented from the perspectives of: curriculum detail and structure, teaching methods and guidance, use of teaching materials, flexibility and integration of games, consideration of mathematics anxiety, teacher motivation and support for innovation, integration of digital tools and gamification, as well as curriculum obligations.

Table 1: Results of the curriculum analysis

Mathematics Curriculum Comparison	Finland	Netherlands	Croatia	Malta	Portugal
Curriculum Detail and Structure	National framework, clear goals, local flexibility	Greater school autonomy within national objectives	Highly detailed curriculum with defined outcomes per grade	Structured curriculum; variation by school type	Structured curriculum with implementation flexibility
Teaching Methods and Guidance	Pedagogical freedom, recommended practices, hands-on learning encouraged	High flexibility for teachers in methods	Balance of methods encouraged; traditional methods prevail	Some pedagogical recommendations	High flexibility; traditional methods common
Use of Teaching Materials	Aligned with curriculum, supports goals, varied formats	Materials align with objectives; school choice	Teachers supplement textbooks with various resources	Government-approved textbooks aligned with curriculum	Teachers supplement textbooks with various resources
Flexibility and Integration of Digital Tools and Gamification	Supports the use of digital tools, games, and innovation.	Flexible use of games, but integration is not prioritized without assessment.	Games encouraged; limited use and training in grades 7–12.	Games seen as supplementary tools; actual use varies.	Games perceived as supplementary; limited training for grades 7–12.

Mathematics Curriculum Comparison	Finland	Netherlands	Croatia	Malta	Portugal
Consideration of Mathematics Anxiety (MA)	Limited mention, supports positive self-image and attitudes	Limited mention; verification needed	Not systematically addressed	A recent local study suggests growing awareness amongst teachers	Curriculum creators vs. teachers questioned
Teacher Motivation and Support for Innovation	Freedom to teach creatively and professionally	Innovation supported at school level	Encouraged innovation, but traditional practices dominate	Institutional support via guidelines and training	Encouraged innovation, but time/content limits
Curriculum Obligations	Mandatory national goals, implementation is locally flexible	Mandatory, with optional components in secondary education	Mandatory curriculum	Mandatory curriculum	Mandatory content; flexible scheduling

All five countries have national mathematics curricula, but their level of specificity and flexibility varies. Finland and Croatia provide detailed grade-specific learning objectives, with Finland emphasizing a national framework that sets clear goals while allowing local flexibility. The Netherlands gives schools greater autonomy in structuring instructional time and implementing the curriculum. Malta and Portugal offer clearly defined curricula, though private schools in Malta have more freedom in content organization.

Curricula generally recommend rather than mandate teaching methods. Finland emphasizes pedagogical freedom and encourages recommended practices and hands-on learning. Malta includes some pedagogical suggestions, while teachers in the Netherlands and Portugal enjoy broader flexibility. In Croatia, a balance of exposition and exploration is encouraged, though traditional methods are often used due to practical constraints. Across the board, teachers retain considerable autonomy in instructional delivery.

Learning materials in all countries align with national curricula. In Finland, materials are aligned with the curriculum and support learning goals using varied formats. Malta also uses government-approved textbooks, while in Portugal and Croatia, teachers often supplement textbooks with various resources such as handouts and digital tools. In the Netherlands, school decisions influence textbook selection. Although digital tools and games are allowed everywhere, their integration varies. Finland supports gamification, digital tools, and innovation, whereas Croatia and Portugal tend to perceive games as supplementary. The Netherlands encourages game-based learning, while in Malta, games are seen as additional tools.

Mathematics anxiety is rarely addressed explicitly in national curricula. Finland mentions it briefly and supports the development of a positive self-image and attitudes in mathematics. Malta has a recent study indicating growing awareness (Grech, 2024), but overall, MA is not systematically considered. Support for innovation also differs: Finland allows teachers freedom to teach creatively and professionally, and institutional support is present in Malta. Croatia and Portugal face challenges due to time constraints and heavy content loads. In the Netherlands, innovation is supported at the school level.

Despite the differences in the mathematics curricula of the five countries, all of them allow and support using digital tools in teaching. In addition, considerations related to MA are still rare. These results are encouraging for developing a digital learning game targeted to mitigate MA. Implementation of such game may require a customised approach in each country.

3.6 Teachers' eQuestionnaire and Focus Group Interviews

So far, we have preliminary findings as 13 Finnish teachers who teach mathematics in grades 2 to 9 have responded to the teachers' eQuestionnaire. All respondents reported observing signs of math anxiety among their students. Two teachers stated that they notice signs of math anxiety often, nine said sometimes, and two reported observing it rarely. The most common indicators of math anxiety observed by the teachers include students having difficulty concentrating during math lessons, expressing negative emotions toward mathematics, and avoiding or not completing math-related tasks.

To help students cope with mathematics anxiety, teachers reported using encouragement, reduced assessment pressure, interactive activities, and flexible timing. They highlighted the need for more practical tools and greater collaboration with support staff. Teachers were mainly of the opinion that a digital maths learning game could help students to be motivated and, on the other hand, to repeat their learning sufficiently.

To explore how mathematics anxiety is perceived, identified, and addressed in school settings, we conducted semi-structured thematic interviews with seven teachers. This qualitative approach allowed a flexible examination of teachers' lived experiences and professional insights. At this stage of the research, interviews were conducted exclusively with primary school teachers. The interview guide was structured around five thematic domains: identifying mathematics anxiety; effects of MA on learning; support strategies used by teachers; school-level support; and opportunities for digital game-based learning.

Teachers identified mathematics anxiety across all primary grades, with older students articulating it more clearly and younger students showing indirect signs. Anxiety was often linked to academic pressure, attention difficulties, and peer comparison, particularly in test settings, and intensified by the evaluative nature of mathematics. While anxiety reduced engagement, performance, and motivation, supportive environments and individualized approaches were seen to improve students' experiences.

Teachers addressed MA using encouragement, differentiated tasks, and small group support, adjusting their strategies to students' developmental needs. However, formal school-level support was limited, relying largely on peer collaboration, with special education services often insufficient and welfare professionals focusing on general well-being. Teachers saw digital game-based learning as a way to boost motivation, offer safe practice spaces, and support students with mathematics anxiety. Adaptive features, clear structure, and storytelling were especially valued, while flexibility between digital and paper-based formats was considered important. Students using digital tools before assessments often performed better, suggesting games' potential to reduce anxiety and improve learning outcomes.

3.7 Students' and Parents' eQuestionnaires

The results of the parent and child eQuestionnaires are preliminary, as data have so far been collected only in Finland. The eQuestionnaires were open only for 11 days before this initial analysis, during which 22 students and 104 parents responded. Of the parent respondents, 9 % had children in grades 7-9, 61 % in grades 4-6, and 31 % in grades 1-3. The high response rate suggests that parents view the topic as important. The most common signs parents observed when their children experienced difficulties in mathematics were frustration, giving up, and feeling inadequate. Nearly half (49 %) reported their children faced at least some challenges in mathematics learning, and 74 % had observed negative emotions during maths tasks or exams, most commonly frustration, giving up, and feelings of inadequacy. Interestingly, 13 % of parents stated they often noticed negative feelings, underscoring the persistent nature of these emotional responses.

Of the students who responded to the survey, 15 were aged 11, five were aged 12, one was aged 13 and one aged 15. In total, 21 students said they liked maths at least sometimes. When asked how they felt when they had to solve a difficult mathematical problem, students were allowed to choose as many feelings as they wanted. The reported emotions included: happy (4), excited (2), confident (9), okay (12), nervous (3), frustrated (4), unsure (2), annoyed (1). Notably, none of the students reported feeling bored or anxious during math task.

To summarize, the preliminary findings reveal that this design of comprehensive needs analysis is valuable and suitable for need mapping offering a recognisable and multifaceted view to the issue. Teachers consistently reported observing signs of MA, most seen as difficulty in concentrating, negative emotions, and task avoidance. While teachers employed strategies such as encouragement, reduced assessment pressure, and interactive activities, they also expressed a need for more concrete tools and greater collaboration with special education professionals and school psychologists.

Despite the early-stage nature of the data, the students' and parents' questionnaires offer valuable insights. Although the term "anxiety" was not explicitly used in the student questionnaire, feelings such as frustration and uncertainty emerged when facing difficult math problems. The terminology used in the student questionnaire was intentionally kept neutral to avoid priming, but this also highlights the challenge of identifying MA in younger learners, who may lack the vocabulary or self-awareness to articulate their emotional experiences. Meanwhile, nearly three-quarters of parents reported observing negative emotions in their children when engaging with mathematics. This emphasizes the role of families in identifying and addressing MA and suggests that future interventions may benefit from actively involving parents alongside educators.

These findings emphasize the potential of digital games as supportive tools. Based on the literature review five design principles were identified to guide the development of the first version of the game. Teachers saw digital games as motivating and helpful – particularly when they include features such as adaptivity, clear structure, and emotionally safe environments. However, such tools should complement, not replace, traditional

instruction and be paired with teacher professional development. Further visualisation of the game design as well as the learning process are our future work.

Limitations include the small sample size and the focus on a single country at this stage. However, the results already offer valuable input for the co-design of a game that targets both emotional well-being and math engagement. As the research expands across partner countries, a more comprehensive understanding will guide the game development and teacher training program.

4. Conclusion

This study presented early findings from a multinational needs analysis supporting the development of a digital learning game and teacher professional development programme to address mathematics anxiety (MA). The needs analysis consisted of literature, curriculum analysis, questionnaires and interviews. The curriculum analysis in five European countries emphasised the need to further address MA and demonstrated the potential for implementing digital games in teaching across all these countries. Based on the literature review, key design principles for such games include scaffolding, adaptive difficulty, narrative and storytelling elements, personalised feedback, and emotional regulation support, along with motivational gamification elements.

MA was widely recognized by teachers and parents, who identified a need for concrete tools, emotional support strategies, and stronger collaboration among school professionals. The enthusiasm of parents and teachers to participate in this study indicated that the topic is truly important. Digital games were seen as a promising complement to traditional teaching when designed with adaptivity, emotional safety, and motivational features. Although the current data are limited to Finland, they provide valuable direction for the game's co-design and related teacher training. As research expands across partner countries, it will further strengthen the foundation for an inclusive, research-informed intervention promoting mathematical learning and well-being.

Ethics declaration: This study did not require formal ethical clearance. However, all participating teachers, students, and parents were fully informed about the study and its purpose. Participants reviewed and accepted the data protection statement prior to participation. For students under the age of 15, written consent was obtained from their parents or legal guardians. We obtained research permission from the Department of Education of the City of Pori to conduct the study in schools within the region.

AI declaration: AI tools were used to support language editing, organize section titles, and identify repetition during manuscript preparation. SciSpace AI assisted in identifying literature sources, and ChatGPT was used selectively to refine text style, improve clarity, and structure ideas for the game mechanics section. All final content was critically reviewed and revised by the authors.

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