Educational games and their impact on mathematics anxiety in university students

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Abstract

This study explores the potential of educational computer games to reduce mathematics anxiety among university students at the University of Sheffield and extends existing literature by mapping everyday mathematics activities and identifying design attributes linked to anxiety. A systematic review of mathematics‑anxiety scales informed the selection of the instrument used in this work, and four mixed‑methods studies were conducted, combining pre/post questionnaires, diary studies, eye tracking and interviews. We observed that playing educational games resulted in a modest 13% reduction in self‑reported mathematics anxiety over a 30‑day period. Eye‑tracking data revealed that participants with higher mathematics anxiety spent more time fixating on problem statements than on potential solutions, suggesting that working‑memory constraints may underlie some of their anxiety. Study 2 expanded Bishop's (1988) framework of everyday mathematics by identifying a new "Predicting" category (e.g. estimating dimensions, costs or time), underscoring the breadth of mathematics embedded in students' daily lives. Diary entries also showed that fluctuations in mathematics anxiety closely mirrored general anxiety, pointing to the importance of broader wellbeing when designing interventions. Familiar real‑life contexts and customisable difficulty levels were found to enhance engagement and reduce anxiety, and these insights were synthesised into a fishbone model of game attributes that affect mathematics anxiety. However, the evidence is limited by the small, self‑selected sample (n = 17), the adaptation of the MARS scale for a UK context and the exploratory design of the study, which restrict generalisability. Nevertheless, the research offers a preliminary framework for understanding how educational games might influence mathematics anxiety and provides practical recommendations for game developers and educators seeking to foster positive attitudes toward mathematics through gaming interventions.

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1. Introduction

The research described in this thesis aimed to investigate the use of educational games in addressing mathematics anxiety among University of Sheffield students. This introduction will highlight the background for the study based on the literature on educational computer games and mathematics anxiety. This is followed by a discussion on what makes this study original both in terms of the demographics of the participants and types of game used as a potential treatment for mathematics anxiety. The chapter concludes by stating the research aims and objectives and how they were formed, based on the background of the study, additionally explaining the processes behind the objectives

1.1. Researcher's background and motivation for the study

The study follows on from the researcher's master's dissertation, which investigated whether conceptual mini-games are an effective e-learning resource (Bonne, 2010). A conceptual mini-game is defined as "a game with multiple levels consisting of [sic] fluctuating difficulty, that takes less than four hours to play, and teaches a single concept" (Bonne, 2010, p.22). In the study, it is suggested that such games could be used to teach abstract mathematical concepts that students struggle with in computer science courses and which are known to contribute to high dropout and failure rates (Gomes & Mendes, 2007; Lahtinen et al., 2005). A meta- review of the literature was conducted to develop a set of requirements for an effective e-learning resource. "Effective", referring to the degree to which games teach the intended concept (Illanas Vila et al., 2008). The games, when measured against these requirements, were found to be easy to use, requiring minimal computer resources, while being compatible across different browsers and devices. However, the games did not possess any knowledge-management features to enable knowledge-sharing amongst users, or any authoring tools to allow customisation of the games for varying teaching requirements.

Bonne (2010) concluded that for mini-games to be an effective e-learning resource, separate applications would have to be used alongside the games that provide both knowledge-management features and customisation capabilities so that teachers can tailor content toward their students depending on their demographic and stage of learning. There was only one platform discovered before the Study 1 study that embed games on a platform that enables knowledge sharing as well as customisation capabilities, albeit through AI recommendations. Games from this platform (Mangahigh) were used throughout the study.

One limitation in the researcher's previous study (Bonne, 2010) was that the requirements for e-learning do not consider individual phenomena such as mathematics anxiety. If the games can reduce mathematics anxiety this may improve motivation to study, making them more effective for learning. Furthermore it was entirely literature-based. A study involving real participants who can be observed and interviewed can ultimately yield richer data on the students' experience playing the games, thus potentially creating a model for a game that more intimately addresses the learners needs, pain points and expectations (Marrelli, 2005).

1.2. Significance of a model-based approach

Previous studies have used models to tackle complex educational problems, providing a clear framework for understanding and reducing anxiety in learning environments. Research has shown that models can identify the variables contributing to educational challenges. For example, (Maloney & Beilock, 2012) developed a model that explains how working memory and anxiety interact to affect maths performance. Thus a model could help examine and combine factors that influence mathematics anxiety

Models can also predict outcomes based on different variables, potentially allowing researchers and educators to foresee the impact of specific game attributes on mathematics anxiety. For example, (Ashcraft & Kirk, 2001) used a model to predict the impact of anxiety on arithmetic performance, finding that their model's variables had significant predictive power.

Additionally, models provide a structured framework for designing interventions to reduce mathematics anxiety. They help identify key attributes that can be changed to reduce anxiety and improve learning outcomes. Hembree (1990) used a model to develop specific interventions for reducing maths anxiety, showing significant improvements in student performance.

Moreover, models can be tested and refined, leading to better understanding and solutions for mathematics anxiety. Repeated testing of models, as shown by Hopko et al. (2003), led to more detailed insights into the cognitive processes behind maths anxiety and informed better intervention techniques.

Several studies have used models to solve educational problems, proving their value. For instance, the Cognitive-Affective Model by Ashcraft and Krause (2007) combines cognitive and emotional components to explain how anxiety affects maths performance, providing a comprehensive framework for interventions. Similarly, Wigfield and Eccles (2000) used the Expectancy-Value Theory Model to explore how students' expectations and values related to maths impact their performance and anxiety, leading to targeted strategies to increase motivation and reduce anxiety. Furthermore, a meta-analysis by Dondio (2023) investigating whether games reduce maths anxiety highlighted the need for games specifically designed to address maths anxiety, and developing a model for this purpose is a way to meet that need.

1.3. Background

The 2022 PISA assessment revealed a significant decline in math performance across the OECD, marking an unprecedented drop. Compared to 2018, the average performance decreased by nearly 15 score points in mathematics—equivalent to losing three-quarters of a year's worth of learning. One contributing factor is mathematics anxiety. In 2012, only 26% of students reported feeling anxious when solving math problems, but by 2024, this figure had risen to 40% (OECD, 2012; OECD, 2022).

Many students arrive at university underestimating the demand for mathematics for their chosen courses. A report by Hodgen et al., (2014) found that while an increasing number of students hold an AS or A Level in mathematics, the majority of UK students arrive with only a GCSE-level mathematics qualification, thus arriving at university having done little to no mathematics for 2 years or more. Additionally, while many universities have departments dedicated to offering extra support in mathematics, few students make use of this support. Course choices are promoted from the students' own socio-economic background, with the students from less educated families more likely to study law, business, and other social sciences over STEM, whereas students from more educated parents choose STEM over social sciences (Codiroli Mcmaster, 2019).

Mathematics anxiety is not just a problem for arts and humanities students: many students doing mathematics, statistics, and engineering courses experience the same phenomenon, often forcing students to drop out of their chosen course (Fortin et al., 2013; Zeidmane & Rubina, 2017; Makaka et al., 2023)

Furthermore, student interest in enrolling on mathematics-heavy courses is falling, with students reporting all-round low levels of enjoyment of mathematics (Onebunne & Onyinye, 2019). In 2022, only 39% of university students in the UK reported interest in studying mathematics, down from 56% of students in 2012. The numbers were determined by past experience with learning mathematics, including students' relationships with tutors, emotional attitude and values towards mathematics, past application of mathematical problems, use of technology, and importance placed on examinations (OECD, 2012; OECD, 2022; Zhang et al., 2019).

Educational computer games have since been used as an intervention to improve mathematics learning for decades (Çankaya & Karamete, 2009; Divjak & Tomić, 2011). Educational computer games consist of games teaching a particular subject or topic via an electronic device with a screen. In general, educational computer games have seen substantial increase in usage, providing engaging content with customised feedback. They are known to instill more positive attitudes towards mathematics in students of all age groups (Mavridis et al., 2017), however little is known on whether they affect mathematics anxiety, particularly what elements of the game have any particular impact. This is despite mathematics anxiety being an increasing concern in STEM education (Dowker et al., 2016). Dondio et al. (2023), in their meta analysis of research on using games for mathematics anxiety, conclude that there is not robust evidence about the impact of digital games, but that could be due to a lack of attention to the features needed specifically in a game aiming to reduce mathematics anxiety. However, it highlights that longitudinal interventions tend to be more effective. A key takeaway is the need for maths anxiety game design:

> "The need for maths anxiety-aware game design is a future research direction rather than a limitation of the included studies. The authors of this meta-analysis did not find any systematic study linking game features to maths anxiety levels, and our suggestion is to embed maths anxiety directly into game design to improve games' efficacy. To date, we have found a very limited number of games where game features were designed with the explicit goal of reducing MA." (Dondio et al., 2023, p15)

This suggests that future research should focus on designing games specifically targeted at addressing maths anxiety, identifying the most effective game features for intervention. To address these gaps, a structured approach, a model could aid game designers in systematically identifying and integrating features that mitigate maths anxiety.

A few studies testing the impact of educational computer games on mathematics anxiety have focused on primary school aged children with mixed results, perhaps due to the studies using different platforms for the games. For example, Verkijika and De Wet (2015) used BCI (Brain Computer Interface) which featured its own game via a headset which was found to reduce mathematics anxiety, another study by Hung et al. (2014) used a game based learning environment using eBooks, which was found to have no significant changes in mathematics anxiety.

1.4. Originality

As previously stated, most studies researching the psychological effects of educational games report their impact on motivation (Girard et al., 2013). However, it is known that even when a student is motivated to learn, mathematics anxiety can hinder their motivation to study as well as to perform under pressure during tests, negatively affecting their exam results (Young et al., 2012; Zakaria & Nordin, 2008).

One study has attempted to assess whether educational computer games could potentially reduce mathematics anxiety for children at primary school level. In this particular study while anxiety appeared to decrease, the results were not significant due to the small sample size used (Núñez Castellar et al., 2014). However, a study by (Erhel & Jamet, 2013) showed that educational computer games can be an effective way to increase motivation to learn for university students. Therefore, it is worth investigating whether educational computer games can reduce mathematics anxiety for university students too.

As such, this study focuses on students at university level, as most studies have targeted primary and secondary school education as participants (Gresham et al., 1997; Tokmak et al., 2013; Van Eck, 2006; Dondio, 2023) with games aimed at the primary and secondary school age range children. This is despite the fact that mathematics anxiety is shown to affect students of all ages (Morris, 2007). Furthermore, the average age for a gamer is 33 years old (up from 30 in 2012), meaning adults are more of an appealing target audience for educational computer games (ESA, 2012, 2019). Additionally, as the researcher is based in the same university as which the study took place, such participants are more easily accessible than those in primary and secondary schools.

1.5. Research aim

To develop a model to identify attributes of a game that impact mathematics anxiety.

1.5.1. Objectives

1.5.1.1. Review the literature to identify mathematics anxiety scales and computer games that could potentially be used for data collection

Having identified some of key findings and a need for the study from the literature on mathematics anxiety and games for the background of the study, the literature was researched in more detail to form a detailed methodology. The literature review begins with an overview of educational games, discussing the differences between serious games and gamification as the terms can sometimes be used interchangeably (Barber, 2019; Bhasin, 2014). Various technological formats of the games (e.g. mobile games, VR) and impact they had on mathematics learning are addressed. The second part of the literature review defines mathematics anxiety, the causes; current methods of reducing mathematics anxiety; as well as similarities with and differences from, other types of anxiety, taking into account how they may affect each other in an educational setting. The literature review also defines educational games and discusses their effectiveness in the STEM (Science, Technology, Engineering, Maths) fields.

A systematic literature review of different mathematics anxiety scales was also undertaken, comparing their validity and reliability. This helped the researcher decide which scale to use for the study. Existing literature involving educational games and mathematics anxiety was reviewed to determine which games could be sourced and used for the study, as well as a particular methodology to adopt in evaluating their effectiveness.

Many different games and their platforms were evaluated throughout the study to identify which one would be most suitable for Study 4. All games differed in terms of their UI (user interface), user flow and general difficulty of the challenges. It became necessary to find out which game participants found the most engaging to avoid too high a dropout rate for Study 4. Three games were chosen to be tested in Study 1.

1.5.1.2. Investigate how mathematics is used in everyday lives of University of Sheffield students

Much of the literature agrees that stories within educational games increase player engagement. (López-Arcos et al., 2017; Mweli, 2018; Navarro-Remesal & Zapata, 2019). The stories need not be elaborate for students to want to play more, for example, as seen later in the study, the now unavailable BBC's Giving Change game, involves playing the role of a till worker counting and handing change to a customer for cash. There is no dialogue, just simple interaction with money, however students felt the game was more relatable and reduced their anxiety about mathematics due to the everyday theme and they chose to play this over games with a more abstract theme. Therefore a separate investigation was made into what activities students undertake in their everyday lives that involves maths, so that this could be incorporated into the final model of a game that reduces mathematics anxiety.

1.5.1.3. Investigate the impact of games on mathematics anxiety in University of Sheffield students

The third objective of this study was to evaluate whether educational computer games, particularly those used in this research, are effective interventions for mathematics anxiety. Studies 1 and 3 employed different variations of a methodology derived from games user research literature (Drachen et al., 2018) to identify the most feasible approach for Study 4. The findings from these initial studies informed the design of Study 4, which was structured as a month-long mixed methods investigation. This study incorporated data collection techniques commonly used in game studios, such as diary and lab studies (Garcia-Ruiz, 2017; Hillman et al., 2016), alongside validated scales for measuring mathematics anxiety (Dowker et al., 2016; Suinn & Winston, 2003).

All studies included a game usability evaluation conducted in the university's iLab, where participants' interactions with the game were observed and recorded, followed by an interview about their experience. The iLab is a dedicated research space equipped for human-computer interaction studies, including eye-tracking software for detailed behavioral analysis. The methodology and findings of Studies 1, 3, and 4 are detailed in subsequent sections, with the mixed methods approach further outlined in Chapter 3.

1.5.1.4. Identify game attributes that impact mathematics anxiety

In order to form a model for a game that affects mathematics anxiety, investigation is necessary into what particular attributes of the game affect mathematics anxiety, in particular the user interface, gameplay and educational challenges of the game (Law & Sun, 2012). Several other instruments were adopted for Study 4 such as eye-tracking and Facereader: furthermore this also became an opportunity to identify whether there is a correlation between facial attributes and mathematics anxiety, providing an additional contribution to knowledge as little to no studies have researched these factors.

Having formed the research aims and objectives, a review of the literature was explored in more detail. This helped determine a precise methodology and instruments to use for data collection and analysis.

2. Literature review

This literature review begins by forming a definition of educational games and mathematics anxiety based on existing literature that will be used throughout the study. Examples will be provided on how educational games have been used for STEM learning and skill development in previous research involving students and their effectiveness. Past literature on conceptual mini-games is also covered: these are browser-based games tested in the researcher's masters dissertation for their effectiveness in teaching maths. The review by Bonne (2010) is summarised here due to browser-based games being tested as a potential treatment for mathematics anxiety throughout the Study 1, 3 and Study 4. Furthermore, the causes and symptoms of mathematics anxiety will be identified, alongside differentiation between mathematics and other types of anxiety that show similar symptoms. Various existing approaches to overcoming mathematics anxiety will be reviewed. To determine what mathematics anxiety scale to use for the study, a systematic literature was carried out detailing the validity and reliability of scales used for different studies. Lastly, examples of games that have been used for previous mathematics anxiety studies will be presented; this is to identify any trends or gaps in the research and provide indication of what game to be used for the study.

2.1. Educational computer games

2.1.1. Defining educational computer games

Educational computer games come in many different formats, purposes and aimed at varying demographics (Bylieva & Sastre, 2018; Petri & von Wangenheim, 2016), with computer games being more widely utilised than board games (Zagal et al., 2006), though board games have seen a resurgence in the COVID-19 era (Hall, 2020). Due to the variety of games available in this domain, it was necessary to form a definition to find games to target for testing in this study.

Definitions of educational games vary greatly depending on the context of the research. For example, in a study on collaborative games Sauvé et al., (2005) defined them as:

“…an artificially and fancifully created situation in which students are placed in a position of conflict and confrontation as they often have to compete or cooperate with each other”. (Sauvé et al., 2005)

However, it may be the case that the game selected for this study is a single player game, with many not including multiplayer scoreboards for the purpose of competition (Martin, 2012), as such, this broader definition would be more applicable.

“…educational games can be considered as computer-assisted instructional tools and techniques in which skills and chance are combined and implemented on previously acquired information and gained experiences” (Anastasiadis et al., 2018)

One author who conducted a user engagement study of educational games is one of the few using a more holistic definition, identifying three dimensions. When referring to educational games throughout this thesis, this definition will be used.

“(1) a game that teaches a certain subject, concept or topic, (2) a game that reinforces or furthers one’s intellectual pursuit in an area or discipline, or (3) a game that assists people in learning a mental skill as they play the game (i.e., physical and motor skills are excluded)" (Nah et al., 2012, p.2)

2.1.2. Educational value of computer games

Educational games offer significant benefits for knowledge acquisition and motivation (Garris et al., 2002). Recent meta‑analyses strengthen this view: *Gui et al. (2023)* conducted a meta‑analytic review of digital educational games in STEM education and found that digital game‑based STEM learning has a medium‑to‑large effect ($g = 0.624$) over conventional instruction and that adding specific design elements yields a small‑to‑medium additional benefit ($g = 0.301$). *Tene et al. (2025)* similarly concluded that serious games can improve knowledge acquisition, skill retention and motivation, but cautioned that implementation often faces technological and training barriers. These findings reinforce that educational games are not merely supplemental; they can be structured interventions capable of driving meaningful learning outcomes.

Many studies have highlighted the educational benefits of computer games for a wide range of purposes, most of which focus on their effect on children and adolescents. Griffiths' (2002) review of the literature found games helped to improve language, reading, basic mathematics as well as social skills in children with severe developmental and learning difficulties. Parents of children with attention deficit disorder reported fewer truancies, drop-outs and better grades as a result of linking video games with brainwave biofeedback. Children with diabetes were found to have improved self-care, communication with parents, and reported a reduction in medical visits due to an educational game designed to enhance self-care skills. Adolescents playing an educational HIV/AIDS prevention game became significantly more knowledgeable about contraceptive practices and felt confident in their ability to apply their knowledge in real life.

In a later literature review on the use of games for learning Mitchell and Savill-Smith (2004) found that the use of computers by children who were gamers made them better at adapting to a more IT-oriented society. The handling of imagery in alternative locations on-screen is shown to increase spatial awareness (i.e. a sense of distance between one object and another). Similar to Griffiths (2002), Mitchell and Savill-Smith (2004) also cite cases where games have been used to treat attention deficit disorder, increasing student retention over traditional teaching approaches. More related to this researcher's study, computer-based mathematics games were shown to be very effective at improving mathematics exam scores (more so than other subjects) in high school age students.

Tobias et al. (2014) whose focus was on learning transfer in educational computer games (i.e. the learning benefits of games transferring to school, work or everyday life), found that participants experienced better transfer when playing games that closely simulated external tasks. For example, aircraft pilots found that games simulating the inside of an aircraft cockpit (first person view) enabled them to perform better when flying in real life. This is in contrast to games where the camera was placed outside of an aircraft (third person view). That said, the literature demonstrated that while users do learn from educational games, there is less evidence of transfer taking place, with many game designers required to close the gap between games and real-life external tasks.

A more recent review by Boyle et al., (2016) who explored the more general benefits of educational games, identified a regularly emerging advantage of knowledge acquisition. Unlike previous reviews, there was a comparison with entertainment games from which a broader range of benefits were identified depending on the type or genre of game. Overall, the benefits included affective changes (increased feelings of flow and motivation), cognitive behaviour changes (improved problem-solving skills/ability to identify causes and solutions), perceptual changes (enhanced ability to see and give meaning to visual information) and physiological changes (better physical fitness, in particular as a result of exercise games). The most frequently occurring topics being taught using these games were in the STEM and health fields.

Other recent studies have attempted to evaluate the value of educational games from the learner's perspective. For example, Mohsen et al. (2019) found that students using business simulation games on their degree felt their ability to understand concepts had improved, along with their skills development in decision making. This was due to an increase in confidence built up over time as through the game where students were able to make important decisions in a risk-free environment.

One current issue from current research is that while many studies report positive results in terms of learning outcomes (student knowledge and skills as well improvements in performance in a professional setting), few studies perform any reliability testing to evaluate whether the same game produces the same results over time. Additionally, it is unclear whether there are behavioural changes in the learning process, and many studies lack continuous progress monitoring (Abdulmajed et al., 2015).

Most studies focus on games encouraging interest and skill development in numerical and technical subjects; only a few studies have occurred which evaluate a game's effectiveness for encouraging interest in the arts. For example, Manero et al., 2015 found that educational video games aiming to promote theatre to high school students not only increased interest in theatre plays, but also improved linguistic knowledge.

Few studies evaluate the effectiveness of educational games from a game's usability perspective, focusing more on learning outcomes and confidence in a topic being taught. Usability is a particularly important factor considering it has a high impact on playability and engagement in the game (ChePa et al., 2015), meaning the less user friendly the game, the less people will play and the less learning benefit acquired from the game. Usability focuses on several game attributes which will be adopted in this study, in particular, the user interface, difficulty level, feedback, terminology (Drachen et al., 2018) and potentially extra dimensions depending on further findings in the literature.

2.1.3. Justification of the Game-Based Learning Intervention

Few studies evaluate educational games' effectiveness from a usability perspective; yet usability strongly affects playability and engagement (ChePa et al., 2015). Dondio et al. (2023) conducted a meta-analysis of 16 controlled studies on game-based interventions for mathematics anxiety and reported a small, non-significant reduction overall (*ES* = –0.32). They found that digital games often have a negligible impact (–0.13), whereas non-digital games or longer interventions can produce more substantial reductions. Together with findings on the generally positive learning impact of games, this underscores that well-designed games with clear pedagogical objectives and attention to usability are needed to maximize benefits.

Previous research has shown that digital games can improve learning outcomes and reduce negative affect toward mathematics. Meta-analyses have consistently found small to moderate positive effects of game-based instruction on mathematics achievement (Clark et al., 2016; Wouters & van Oostendorp, 2016). Games appear to foster engagement by embedding practice in meaningful, interactive contexts that sustain motivation (Habgood & Ainsworth, 2011). Evidence also indicates that game-based learning can help reduce mathematics anxiety by reframing failure as a safe, repeatable event and providing immediate feedback (Ramirez et al., 2018). These findings justify the decision to employ a game-based intervention in the present study, since it aligns with established evidence that playful digital environments can support both cognitive performance and emotional regulation in mathematical tasks.

2.1.4. Choice of educational computer games

The preference for educational computer games over other interventions, such as workshops or mindfulness practices, was based on their demonstrated potential to engage users and provide immediate, contextual feedback. These games integrate interactive elements that mirror real-life scenarios, fostering familiarity and reducing anxiety, as highlighted in the literature (e.g., Tobias et al., 2014). Furthermore, computer games uniquely allow for customizability, such as adjusting difficulty levels, which directly aligns with reducing triggers of mathematics anxiety identified in studies like Hembree (1990).

The choice was also informed by logistical feasibility. Other methods, like in-person workshops, require significant time and resource investments, limiting scalability. The computer games, on the other hand, offered an accessible and scalable medium, aligning with the study's aim to explore widely applicable solutions to mathematics anxiety.

2.1.5. Conceptual mini-games

As stated previously, a conceptual mini-game is defined as "a game with multiple levels consisting of [sic] fluctuating difficulty, that takes less than four hours to play, and teaches a single concept" (Bonne, 2010). This type of game has been seldom discussed in the literature.

This is similar to other definitions such as Illanas Vila et al., (2008) who define them more simply as "a mini-game aimed to teach a specific concept". For this study, the Bonne (2010) definition will be used as the study is slightly more recent. These games are typically browser or desktop based, with simple rules, requiring few or a single input (e.g. a mouse click) to navigate, and aimed at high school or primary school age children. Several websites such as BBC Skillswise formerly hosted this precise type of game but aimed at adults, these games were used as a potential treatment for this researcher's Study 1 (see Results section for Ordering Fractions game), though were not taken forward into Study 3 as students found the games boring due to lack of content. Conceptual mini-games differ from the more commonly known serious mini-games (De Jans et al., 2017) in that maths problems are presented in a more abstract form, rather than involving story, characters, camera angles etc. For example, Ordering Fractions simply consists of boxes containing numbers that players are required to arrange in order on screen, whereas other games teaching the same topic games on BBC Skillswise involved arranging pizza, cake slices and other more concrete concepts.

The researcher has already reviewed some of the relevant literature on educational games in his Masters dissertation (Bonne, 2010). The review discussed the link between game-based learning and preferred learning styles, going over a range of learning style models, concluding that there is no link between the learning style of an individual, and the effectiveness of game-based learning.

In the study, various definitions of conceptual mini games are highlighted, with one being formulated to use in the study. The effectiveness of game-based-learning in general is also discussed, identifying mixed results depending on the size of the criteria used to determine effectiveness, i.e. the larger the list of criteria, the less effective mini-games were concluded to be. Where mini games excelled were when they were built for a specific school or university course, rather than a general subject area. That said, larger 3D games were found to be more effective overall due to features allowing multiple ways to solve problems. Games aimed at university level students were confirmed to be as equally effective as traditional teaching methods. The literature review also highlighted the behavioural theories that support game-based learning, as well as the methodologies used for research involving mini-games, which most often involved observation of participants playing a game, followed by the interviews on their experience. Given the same type of game in terms of platform and level of content was used for this thesis, a similar approach to data collection was adopted. There were alternative gaming related treatments to consider, including simply gamifying educational content which are detailed below.

2.1.6. Serious games and educational computer games vs gamification

Many categories of educational games have occurred in the literature. Serious games have their own range of definitions by different authors, with most definitions referring to digital games. In a literature review on the effectiveness of educational games Backlund and Hendrix (2013) define serious games as “games that engage the user, and contribute to the achievement of a defined purpose other than pure entertainment (irrespective of whether the user is consciously aware of this)”. Many authors equate educational computer games with serious games, for example, Dele-Ajayi et al. (2016) who developed a framework of engagement for mathematics games aimed at 7-16 year olds, found serious and educational games and do not offer the same level of fun as entertainment games, but nonetheless were effective form of engaging students in the topic.

Serious games differ from gamification, in that gamification is the application of game attributes to alternative mediums to better engage people in activities. Kapp (2012) defines gamification as “using game-based mechanics, aesthetics and game thinking to engage people, motivate action, promote learning, and solve problems”. One example of gamification e.g. from Jagušt et al. (2018) might be where students are rewarded points for their performance on sections of a standard classroom lesson plan and may also use leaderboards to encourage students to compare scores and compete with each other. Gamification itself has been shown to increase student motivation to learn, however it has a larger impact on students who are internally rather than externally motivated (Buckley & Doyle, 2016). Specific to mathematics learning, gamification has mixed results in terms of student performance depending on the combination of specific game attributes used as an intervention such as timed tests, and furthermore the student's own reaction to types of gamification. The highest performance came from gamification involving a story, competition, and when the game's difficulty could be adjusted to individual performance levels (Jagušt et al., 2018). This suggests educational computer games offering these features could be utilised as a method of controlling mathematics anxiety.

2.2. Gaming platforms

Educational computer games are available on a variety of mediums, mainly mobile phones, computers, web browsers, games consoles and more recently, apps available on TV (Drobics & Smith, 2014). Mobile phones and computers come with their form of anxiety trigger, these stem from addiction to those devices and the amount of work to navigate devices interface, these should be taken into account as the game could impact on mathematics anxiety (Achim & Al Kassim, 2015; Bhattacharya et al., 2019)

2.2.1. Browser games

Most of the literature focuses on browser-based games which simply involve games being played through a web browser (such as Chrome, MS Edge), as they are easiest to set up, only requiring an internet connection and a device containing a web browser. Furthermore, the games are generally simpler and shorter than console games: advances in web technologies such as HTML5, SVG, and WebGL allow browser games to deliver smooth and responsive performance, even in graphically rich environments (Zaqout & Wishah, 2015).

In their systematic literature review, Dahalan, Alias, & Shaharom (2024) show that browser-based educational games can enhance motivation, engagement, and academic achievement, especially in vocational and formal learning settings.

Additionally educational games are publicly funded or freely available to users, eliminating financial barriers to access (Pötzsch & Hammar, 2023).

Therefore browser games were chosen for this study, since they presented fewer technical barriers to study participants, also proved to enhance motivation to learn, were free and would be more straightforward to adopt by teachers in the classroom.

One issue is that most of these types of games are aimed at children and younger adults of primary and secondary school age, making it difficult to find suitable games for adults. Furthermore, many studies involving browsing-based educational games focus on implementing design concepts rather than testing them with real participants (Virvou & Papadimitriou, 2003, 2013), presenting an opportunity to test them with real participants for this researcher's study. That said, where the literature has used browser-based educational games to improve maths ability with students the results have led to improved performance. For example, in a study by (Coştu et al., 2009), Turkish primary school students learning mathematics via a browser-based mathematics game found the game helped make more abstract mathematics concepts more concrete and easier to visualise as well as understand. Students also felt that using the game alongside their curriculum would be beneficial. Lester et al. (2014) also found that when testing a story driven browser-based STEM game to U.S. secondary school students alongside their curriculum, participants made significant gains in learning for both mathematics and science topics being taught.

As browser-based games can be played on computers, one potential hindrance to the participants' learning could be computer anxiety. Studies such as Cazan et al. (2016) found that computer anxiety has a negative correlation with the science grades of students. Moreso, computer anxiety had a negative correlation with the level of experience students had with computers. Therefore it was decided that, for this study, participants would be asked how much experience they had in computer gaming.

2.2.2. Mobile games

Widespread adoption of mobile devices among the student population have made them a potentially ideal platform for educational content. However, the content provided via mobile devices is often less optimal, this is due to apps being developed by software developers rather than educators (Molnar & Frías-Martínez, 2011). There are also more challenging design decisions, such as how to convey learning material that is effective for the reader on mobile sized screens.

Existing mathematics mobile games, however, have proven to be effective for improving learning. For example, in Castillo et al.'s (2019) study of school age (10-year olds) children in the Philippines, students who were previously uninterested in maths, found their ability to learn maths concepts increased by 48.86% after pre-test, post-test examinations. Another study observing the performance of computer science students in Malaysia who were learning linear algebra and discrete mathematics found students learn more effectively with mobile games that encompass the 3i design factors, interface design, interaction design and information design (Yahya et al., 2019). One weakness of educational mobile games is the inability for teachers to customise the content of games based on student needs (Bonne, 2010). However, some studies have attempted to implement such features such as educational content creation, discovering students improved their knowledge acquisition when used both in and outside of the classroom (Molnar et al., 2015). One concern with mobile educational games is that while there are thousands of apps available to students, most are aimed at children, making it harder for educators to find games suitable for college or university level students (Papadakis & Kalogiannakis, 2017). Most studies measure the impact of mobile games on learning but not replayability, despite educational computer games being most effective when multiple sessions occur. One study found that immersion, fun, fantasy and sensation were the most influential factors affecting the replayability of games, however the games were aimed at children. Such factors could be measured for games aimed at university level to identify suitable design features aimed to improve learning (Venter & de Wet, 2016).

2.2.3. Console games

Console games are games requiring a device (such as a video game console) to be played on a television. The player interacts with the game via a controller, joystick or other handheld device containing the buttons required to navigate the game. Some recent and most prominent examples at the time of this research include the Microsoft Xbox, Sony Playstation and the Nintendo Wii. Similar to mobile and browser games, console games do not require as much technical skills to set up and play compared to computer games, which require knowledge of computer hardware and software drivers to ensure the game is compatible. From a usability perspective both console and mobile games buttons contain less buttons on their controller interfaces, whereas with computer games, users are presented with 88 keys on the keyboard, requiring more working memory to memorise and increasing computer anxiety (note that Playstation 4 controllers only contain 9 buttons).

Numerous studies have investigated the impact console based educational games have on mathematics learning. For example, Miller and Robertson (2010) found that with primary school children, console games improved accuracy and speed of calculations, students also experienced growing overall self-esteem. However, research studies focusing specifically on console-based educational games are significantly fewer than mobile and computer games. This could be perhaps because console games require a separate expense in terms of hardware (games console) required to play, whereas most games for PC's and mobile can be played on the devices the user already owns. Furthermore, game developers tend to steer clear of building educational games for consoles as it is more difficult to make a profit, particularly with limited budgets and red tape involved in selling to schools (Crawley, 2015). There is however a latent demand for educational games for consoles, for example DiSalvo et al. (2008), found students who played console games as children, were interested in playing educational console games as adults, however due to games developers primarily targeting school age children the current offerings lacked appeal.

2.2.4. VR games

VR (virtual reality) educational games are relatively new to the educational scene, though have become more widespread thanks to the introduction of VR hardware for PC and game consoles. VR requires the use of a headset to play and also needs to be calibrated with the players eye movement, this makes it particularly difficult to play games without some technical knowledge. Surprisingly few studies have investigated the potential to cause anxiety in its users, rather VR has been used as an intervention to treat anxiety disorders (Martin et al., 2018; Wiederhold & Bouchard, 2014) this suggests that immersiveness in games is a contributing factor to reducing anxiety as the benefits of VR interventions effectively transfer to the real world (Gao et al., 2018).

Where VR games have been used in studies to improve maths skills the results have been largely positive. For example, in the Sweidan and Darabkh's (2018) study of VR usage in Arabic primary schools, the results identified positive sentiment amongst teachers and students. Another study of Norwegian students by Stranger-Johannessen (2018) found pupils in grade 5 (10-13 years olds) were more motivated to learn multiplication following an intervention with a story-based VR game involving buying items from shops. This provides potential confirmation that story-based games which closely replicate the real world could be a more effective tool for learning than more abstract games and with no narrative.

2.3. Mathematics Anxiety

It should be noted that most studies dating back from 1990 were carried out in the USA, where the first mathematics anxiety scale was created. However, while the majority of newer studies also take place in the USA, research has branched out into Europe and the UK, with a minority of studies taking place in India (Chaman & Callingham, 2013; A. Karimi & Venkatesan, 2009). and South Africa (Mutodi & Ngirande, 2014; Verkijika & De Wet, 2015).

Varying definitions of mathematics anxiety have been used in the psychology literature over time. Definitions generally encompass negative feelings a person may experience when confronted with a mathematics problem.

Byrd (1982) views mathematics anxiety as "any situation in which an individual experiences anxiety when confronted with any mathematics in any way".

Ashcraft and Faust (1994) define it as "the feeling of tension, helplessness, mental disorganisation and dread one has when required to manipulate numbers and shapes and the solving of mathematical problems".

Other authors, such as Spicer (2004), simply describe mathematics anxiety as an emotion "an emotion that blocks a person's reasoning ability when confronted with a mathematical situation".

This study will adopt the most widely used and descriptive definition of mathematics anxiety, by Richardson and Suinn (1972) "Mathematics anxiety involves feelings of tension and anxiety that interfere with the manipulation of numbers and the solving of mathematical problems in a wide variety of ordinary life and academic situations." While other definitions could be interpreted to refer to mathematics in an academic setting, this definition is one of the few that more explicitly emphasizes anxiety occurring when dealing with numbers in everyday life, a particular concept that needs to be explored in the development of educational maths games, due to their potential to be an effective intervention (Tella, 2019), and is explored later in the researcher's study.

2.3.1. Justification for focus on Mathematics Anxiety

The decision to focus specifically on mathematics anxiety (MA) stems from its well-documented prevalence and detrimental impact on academic outcomes. *Cipora et al. (2022)* systematically reviewed psychological constructs of MA, arguing that MA is distinct from general anxiety, tends to emerge early in schooling, and affects performance across cultures. They noted that MA research should differentiate trait (long-term) and state (situational) anxiety to better tailor interventions. Given these nuances, domain-specific interventions, such as educational games are warranted to address MA directly. MA affects approximately one-quarter of university students (Ashcraft & Moore, 2009) and is consistently associated with reduced achievement and avoidance of quantitative courses (Dowker et al., 2012; Carey et al., 2016). Prior research also links MA with cognitive interference, reduced working-memory capacity, and decreased confidence (Ashcraft & Ridley, 2005). Addressing MA is therefore central to improving mathematical engagement and performance. Positioning the intervention within this framework ensures the study contributes to a pressing area of educational psychology concerned with mitigating affective barriers to learning.

2.3.2. Symptoms of mathematics anxiety

According to (Marshall et al., 2017), there are four known symptoms of mathematics anxiety that occur when students are faced with, or about to be faced with, mathematics problems.

Panic - the individual has persistent feelings of powerlessness and fear.

Paranoia - despite a mathematics problem being difficult or complicated, the individual may feel they are the only person who cannot solve it.

Passive behaviour - the person may conclude that they will never be good at mathematics and avoid doing anything about the issue.

Lack of confidence - feelings of helplessness leads the person to believe they cannot solve a problem. They may guess, rather than attempt to solve answers to the questions, or second-guess their own answers. They may also rely on others to carry out tasks requiring mathematics (e.g. calculating 15% tip for a restaurant bill).

Other authors point to more physiological symptoms including; sweaty palms, feelings of queasiness, heart racing, as well as being unable to think clearly and the occurrence of thought paralysis . Physiological symptoms are particularly important as teachers are often unaware of their occurrence unless explicitly stated by the student.

Numerous behavioural symptoms are also identified. Avoidance behaviour in particular, where students choose to stay away from mathematics classes, procrastinate with mathematics homework, and generally neglect to study mathematics-based course material (Blazer, 2011). Another behavioural factor includes negative self- talk, which Carter and Erna, (2017) give an example of in their study of mathematics anxiety in the science classroom.

“I was never any good at math.” “This is probably a stupid question” “I know that I should know how to do this.” “What’s the use? I won’t be able to do it anyway.” “Everyone knows what to do but me.” “I don’t have a math/science mind.” Carter and Erna (2017).

The effects of negative self-talk consumes mental energy and time focused on the negative perception of maths rather than attempting to solve problems. The lack of focus means reduced performance, leading to further anxiety about mathematics as more maths problems arise in class.

An additional symptom known from much older literature is referred to as “dropped stitch” (Tobias, 1993). Dropped stitch is the concern about crucial information missing from the material, for which students worry will hinder their ability to progress with their mathematics learning. Sheila Tobias (1993) states that this is due to the progressive nature for which maths needs to be taught for students to learn effectively.

Other studies take a quantitative approach to identifying symptoms of mathematics anxiety. The most frequent symptom affecting 29.5% of students was memory loss when under time pressure (both with summative and formative tests). This is further evidence that timed testing should be a factor to consider more carefully when creating educational maths games aiming to reduce mathematics anxiety. The second most frequent symptom falls into the physiological category, taking longer breaths, a natural response to ease anxiety. Students with mathematics anxiety see maths as something to be frightened of, affecting 26% overall. 25% of students experienced an inability to concentrate on the problems presented particular when in an exam environment. Students in this case found their lack of interest in a topic forced them to think about other subjects they deemed more interesting (Anindyarini & Supahar, 2019). This means for this current study it is important that game content is engaging enough to keep students focused on the maths content.

2.3.3. Causes of mathematics anxiety

Literature reviews provide a nuanced picture of the origins of mathematics anxiety. Rada and Lucietto (2022) survey research and conclude that mathematics anxiety often stems from multiple, interacting factors—ranging from teacher behaviours and classroom climate to previous negative experiences and pervasive social stereotypes. Purnamasari's (2023) systematic review echoes this view, highlighting eight recurring antecedents, including fear of failure, insufficient support from instructors, and cultural narratives that label mathematics as inherently difficult. These reviews jointly affirm that mathematics anxiety is not caused by a single factor but emerges from a complex interplay of personal history and socio-educational context, reinforcing the importance of multifaceted interventions to address it.

2.3.3.1. Teachers

According to Usop et al. (2009), teaching is the most important factor affecting mathematics anxiety in undergraduate students. Within teaching are more specific factors. The teacher may look uncomfortable or uninterested in teaching mathematics. The material may be taught in a way that is too abstract or irrelevant to real-world problems. Students could also be burdened with too many problems in a given session, leading to fatigue, or given too many questions to solve in a short space of time. It could be said that various features in a games design such as the amount of time given for solving problems, real world application, and methods used to make the game engaging would have to be considered if such tools are capable of reducing mathematics anxiety.

2.3.3.2. Parents

Mathematics anxiety can also be created or worsened by a student's parents. Such factors may involve being unable or reluctant to help with academic problems. Parents may not get involved in the student's education at all, overlooking discussion about their anxiety or leaving students to try and deal with mathematics anxiety on their own (Silva et al., 2006). It is also important that parents work together with teachers to ensure their students feel confident learning mathematics (Rossnan, 2006).

2.3.3.3. Peers

Comparing grades with those of their friends, and fear of criticism from friends over wrong answers can create a sense of isolation and inferiority that worsens mathematics anxiety (M. R. Smith, 2004). Instead, having friends to study with and share techniques for tackling mathematics problems, coupled with strategies for managing workload, helps reduce anxiety levels as students recognise that support is easily available (Kindermann & Skinner, 2009).

2.3.3.4. Society

Increasing pressure from the media and government pushing the importance of students learning mathematics to improve their jobs prospects and contribution to the economy in general (Cottee et al., 2013), places increased pressure on students to enrol and perform better in mathematics oriented subjects. Shields (2006), discovered that such messages only caused students to feel they could not live up to societal expectations, increasing mathematics anxiety further.

We can analyse the society dimension from a countywide perspective. Countries with high performing students in maths, have been known to have both low and high mathematics anxiety depending on the country.

2.3.3.5. Working memory

Symptoms created from mathematics anxiety are more intense at advanced levels of mathematics, generally the more complex the question, the higher the level of anxiety, as the individual must use more working memory (i.e. the capacity to store numbers and perform calculations in mind (Gathercole & Alloway, 2007). Students with high working memory (able to rely on memory to perform calculations) have been found to be more impacted by mathematics anxiety than those with low working memory (more likely to turn to finger counting, written notes). This was due to persistent feelings of worry demanding cognitive resources that would otherwise be used for performing calculations. Those with low working memory on the other hand, felt less anxious due to having more heuristic problem-solving strategies and tools available (Ramirez et al., 2013).

2.3.3.6. Age

Despite cases where severe mathematics anxiety affects primary school children (Sorvo et al., 2017), overall mathematics anxiety increases with age with attitudes towards mathematics anxiety becoming more negative (Dowker, 2019; Mata et al., 2012). Older studies find that the decline in attitude towards mathematics begins just before children leave primary school (Wigfield & Meece, 1988).

Causes for the increase in mathematics anxiety by age are numerous. General anxiety is known to increase past primary school and hits the highest point during an individual's teenage years (Kessler et al., 2005; Khesht-Masjedi et al., 2019). This could be due to a rise of aversion to uncertainty as well as increasing social comparison at this age, which may contribute to a rise in general anxiety and mathematics anxiety. Furthermore, students are more likely to encounter negative opinions of mathematics from other students, as well as stereotypes about mathematics being hard, gender ability differences, future changes in difficulty in mathematics content, as well as stories and risks of failure. Additionally, students will be told of the greater level work needed to handle abstract maths and larger figures (Cui et al., 2017).

2.3.3.7. Math avoidance

Mathematics anxiety is a self-fulfilling prophecy. As an individual's self-efficacy (confidence in their abilities) reduces, so does their ability to solve mathematics problems, and because performance suffers, this reduces self-efficacy even more. This can encourage mathematics avoidance, causing students to evade courses or everyday situations that require mathematics. Eventually this leaves the individual with little to no mastery or competence in the subject, intensifying anxiety when faced with mathematics problems later on (Allen, 2017; McMullan et al., 2012).

Other studies have attempted to gauge from students what they think are the causes of their mathematics anxiety. The most occurring theme identified by Jameson (2019), who interviewed adult learners, was the last time students studied maths formally. Essentially students who had been out of education longer felt they had more difficulty learning maths than students who had left education more recently.

As such, this agrees with authors such as (Yavuz, 2018) who view the causes of mathematics anxiety as containing three dimensions, environmental, mental and personal factors. In this case environmental factors would be: teachers, parents, peers and society, mental factors would be working memory and personal factors would consist of math avoidance and the last time students studied maths formally.

2.4. Differentiating between mathematics anxiety and other forms of anxiety

In terms of mathematical challenges and anxieties, it is important to discern between maths anxiety, general anxiety, and dyscalculia. Each of these conditions represents a unique aspect of cognitive and emotional experiences related to mathematics. While maths anxiety entails apprehension towards mathematical tasks, general anxiety extends its grip beyond mathematics. On the other hand, dyscalculia involves distinct cognitive difficulties in comprehending mathematical concepts. To accurately differentiate between these conditions and measure maths anxiety while accounting for other forms of anxiety or dyscalculia, a thoughtful approach is essential.

2.4.1. Mathematics anxiety vs statistics anxiety

Certain courses such as those taken by social science students' (e.g. business management, economics) involve some form of maths and number manipulation but focus primarily on statistics: as such it becomes appropriate to differentiate between mathematics anxiety and statistics anxiety. Statistics anxiety (SA) is defined as "the feelings of anxiety encountered when taking a statistics course or doing statistical analyses; that is, gathering, processing, and interpreting data (Cruise et al., 1985). Both mathematics anxiety and statistics anxiety have a negative impact on performance due to increased tension and worry during exams (Paechter et al., 2017). Statistics anxiety has been known to affect around 80% of social science students. Students taking these courses tend to be enrolled on extra quantitative modules as part of their training to complete their degree program. Exposure to statistics problems provokes anxiety and becomes the main source of anxiety for students on their curriculum, hindering their performance on their chosen course (Kimuyu, 2018).

There are numerous differences between mathematics anxiety and statistics anxiety. Statistics relies more on verbal reasoning instead of mathematical reasoning (Buck, 1987), and also invokes more logical skills than mathematics skills (Zerbolio Jr, 1989). That said, mathematics anxiety has been shown to correlate positively with statistics anxiety, i.e. those with high mathematics anxiety are likely to have high statistics anxiety (Birenbaum & Eylath, 1994; Primi & Chiesi, 2018).

A review of statistics anxiety literature by (Baloğlu & Zelhart, 2003) found that just under 50 per cent of variance in statistics anxiety could be attributed to mathematics anxiety. Furthermore, (Malik, 2014) discovered that different factors impacted statistics anxiety or mathematics anxiety in different ways. Only mathematics anxiety varied significantly between genders for example, while only statistics anxiety varied significantly between those choosing STEM courses and those choosing non-STEM courses. However, both statistics anxiety and mathematics anxiety were significantly impacted by mathematics background, while college year had no significant impact on either.

Statistics anxiety itself has shown to have a negative correlation with performance in calculating probabilities, hence for studies measuring statistics anxiety it may be worth finding a game that involves probability as its topic (Primi & Chiesi, 2018).

The causes of statistics anxiety slightly differ from mathematics anxiety, though still fits with Yavuz's (2018) three dimensions of personal, environmental, and mental factors. In this case, statistics is affected by motivation, class anxiety, and the level of engagement of the learner (Frias-Navarro et al., 2018).

Given these differences between mathematics anxiety and statistics anxiety encountered in the literature, it may be the case that any removal of mathematics anxiety may not completely erase statistics anxiety too. As such it may be worth identifying if educational computer games can have an impact on statistics anxiety levels in future studies (González et al., 2016).

Treatment of statistics anxiety also differs from mathematics anxiety, with the literature focusing more on mindset interventions designed to increase the student's confidence with statistical problems (Smith & Capuzzi, 2019).

2.4.2. Mathematics anxiety vs computer anxiety

As the study involves the use of computer games, one issue that may affect the results of the study is computer anxiety. Computer anxiety (CA) refers to "fears about the implications of computer use such as the loss of important data or fear of other possible mistakes" (Sievert et al., 1988).

Computer anxiety occurs and is made worse due to personal traits, in particular, an individual's self-esteem, perception of control over their lives, confidence using computers, and level of anxiety, envy, insecurity and guilt (neuroticism) (Marakas et al., 2000) . Those with computer anxiety are known to feel anxious when using computers in the present, as well as having thoughts of using them in the future. They also possess a negative outlook on computers, their role and their impact on the world (Heinssen Jr et al., 1987). Computer anxiety has also been shown to negatively correlate with computer experience (Gaudron & Vignoli, 2002). A study observing the relationship between mathematics and computer anxiety found those with high computer knowledge possessed lower mathematics anxiety and computer anxiety than those with low computer experience (Lloyd & Gressard, 1986; Suri et al., 2003).

Several factors have been known to alleviate computer anxiety. In a study interviewing students who both had severe mathematics and computer anxiety, working ahead of any deadlines made students feel more confident about being able to finish their tasks, but more fundamentally the ability to understand the topic in the required timeframe. Asking questions also alleviated any stress, as the tutor could take time to explain concepts based on the students preferred learning style (Murphy, 2018).

2.4.3. Mathematics anxiety vs general anxiety

Studies show only moderate correlations between MA and general anxiety ($r \approx 0.3$–0.4). Cipora et al. (2022) and Owens et al. (2012) recommend treating MA as a domain-specific trait, which allows for targeted interventions (such as games) without conflating MA with broader forms of anxiety.

General anxiety is defined by the NHS (2015) as "a feeling of unease such as worry or fear, that can be mild or severe". As such, general anxiety shares some similar symptoms with mathematics anxiety and initially could be mistaken for each other (Owens et al., 2012), for example, found general anxiety similarly demands much of the working memory and cognitive capacity of the individual, making them unable to think clearly and to an observer and creating the appearance of confusion or worry. However, for mathematics anxiety, those symptoms only occur in mathematics environments. Both general anxiety and mathematics anxiety are known to impede academic performance, with studies showing general anxiety being more prevalent overall among university students (Abraham et al., 2017).

A later study found a link between mathematics anxiety, general anxiety levels and mathematics skills in terms of genetics. Genetics have been found to account for around 40% of the variance in mathematics anxiety levels (the other 60% caused by, as previously mentioned, negative past experiences with learning or doing mathematics) (Wang et al., 2014). Essentially, Wang et al. (2014) found that students with a family history of poor mathematics skills and general anxiety are particularly susceptible to mathematics anxiety. In terms of gender, general anxiety is known to be more prevalent among females, whereas with mathematics anxiety, any gender differences are dependent on the country. For example, with Indian university students mathematics anxiety was more prevalent among males (Abraham et al., 2017), whereas other studies identify males having lower mathematics anxiety than females on a global level, with the gap being larger in more developed countries with more gender equality (Stoet et al., 2016).

In the neuroscience field, to further distinguish between mathematics anxiety and general anxiety, a study by Young et al., 2012) observing the effect of mathematics anxiety on the brain using MRI on children found mathematics anxiety was shown by a number of specific brain activity patterns not related to general anxiety at all.

2.4.4. Mathematics anxiety vs dyscalculia

While many varying definitions of dyscalculia exist, most of the literature appears to agree upon its main symptom, that is, difficulty in memorizing and absorbing arithmetic facts (Butterworth & Laurillard, 2010; Landerl et al., 2004; Price et al., 2007; Reigosa-Crespo et al., 2012). Mathematics anxiety differs in that individuals experience difficulty memorizing or learning any mathematics concept. Furthermore there are few to no instruments used to measure dyscalculia, and authors instead rely on standardized arithmetic tests, and compare scores with test-takers in the participant's age group. Those with scores within the 5^{th} percentile of the age group are diagnosed with dyscalculia.

To an observer, when confronted with a dyscalculia sufferer trying to solve arithmetic problems, they could be mistaken for having mathematics anxiety. According to the British Dyslexia Association (The British Dyslexia Association, 2019, those with dyscalculia may actively avoid mathematics tasks they perceive to be difficult, may forget complex procedures used to solve mathematics problems causing slower arrival at answers, and can appear to have weak arithmetic skills. However, there are many symptoms unique to those with dyscalculia including; using addition as the operator even though a question asks them to divide or subtract, furthermore they may have issues understanding the value and positioning of zero in the number system (e.g. as zero means nothing, therefore the zero in ‘101’ may be ignored, making it number ‘11’ instead; Rubinsten & Tannock, 2010).

A significant symptom that may mislead observers, is that dyscalculia sufferers can also suffer from high levels of mathematics anxiety itself, making it initially difficult to identify whether struggles with mathematics are due solely to mathematics anxiety, or whether it is part of the wider problem of dyscalculia. However, there is also a chance that the dyscalculia may not suffer from mathematics anxiety at all, they are often recognised by a willingness to ask for help when needed (Hill et al., 2016).

Measuring maths anxiety in a manner that safeguards the results from being influenced by other forms of anxiety or dyscalculia necessitates a methodological approach founded on careful consideration and expert guidance. Academic research highlights several strategies that can effectively mitigate potential confounding factors and enhance the precision of the assessment. These include: measuring mathematics anxiety, differentiating constructs, statistical rigour and multi-method, longitudinal assessments. These are described further in section 2.4.5.

2.4.5. Measuring mathematics anxiety

To ensure the integrity of the measurement, it is recommended to employ established and validated scales or questionnaires such as the mathematics anxiety rating scale (MARS; Suinn & Winston, 2003) , specifically tailored to gauge maths anxiety. These instruments possess robust psychometric properties designed to disentangle maths anxiety from broader forms of anxiety or cognitive challenges (Hembree, 1990).

2.4.5.1. Differentiation of constructs

A critical step involves crafting assessment items that capture maths anxiety without overlapping with general anxiety or dyscalculia symptoms (Ashcraft & Krause, 2007). Items should be formulated to directly tap into the emotional and experiential aspects tied to mathematical activities. For example, items used by Suinn and Winston’s (2003) MARS, asks readers to think about how they feel about doing maths tests, calculating the bill at a restaurant, figuring out budgets and other everyday life situations involving maths. This differs from general anxiety scales which are not situation-specific, and assess symptoms like excessive worry, tension, and nervousness across broader aspects of life (Spitzer et al., 2006). This also differs from dyscalculia assessments, in that they test a reader's ability to complete specific computation problems, such as counting accurately, positions of digits, and remembering key facts, with some tests measuring the person's reaction times to maths problems (Haberstroh & Schulte-Körne, 2019).

2.4.5.2. Statistical rigour

Employing robust statistical methodologies is crucial for controlling potential confounding variables. Statistical techniques like regression analysis can effectively identify the unique contribution of maths anxiety while mitigating the impact of general anxiety or dyscalculia (Suárez-Pellicioni et al., 2016).

2.4.5.3. Multi-method, longitudinal assessments

A holistic understanding of an individual's experience with maths anxiety can be gleaned by combining various assessment methods, including self-report questionnaires, behavioural observations, and cognitive evaluations (Dowker et al., 2016). Incorporating clinical interviews enables the collection of qualitative data that can effectively discern between different types of anxiety and cognitive challenges. Observing the patterns and changes in maths anxiety over time through longitudinal assessment provides insights into its consistency amidst potential fluctuations in general anxiety or cognitive abilities (Field et al., 2019; Piccirilli et al., 2023).

2.4.6. Mathematics anxiety and physiological symptoms

It is possible to measure mathematics anxiety by measuring cortisol changes to the participant as they encounter maths problems. Cortisol secretion increases as an individual becomes more stressed (Hellhammer et al., 2009). It can be measured either in the individual's blood sample, urine, or saliva. Studies where students had been given statistics exams while having their cortisol levels measured found cortisol levels rise before the exam and decline after the exam. Other studies identified similar results but only in students with high working memory. Students with low working memory demonstrated a positive correlation between performance in mathematics exams and cortisol levels (Mattarella-Micke et al., 2011; Pletzer et al., 2010).

Thus with most existing studies the relationship between mathematics anxiety and cortisol has not been significant and should not replace mathematics anxiety scales.

EEG/ERP are other potential method measurement tools but focusing on brain imagery. EEG (or electroencephalogram) examines electrical activity in the brain. Communication between brain cells requires the transmission of electrical impulses. An EEG can be used to identify potential problems with the brain by recording brain wave patterns and sending these signals to a computer to store the results. It requires the participant to attach small metal discs to their scalp which are attached to a computer. ERP (event related potential) is the same concept, but instead, some kind of stimulus is shown to the participant (e.g. a video, image, game), and the activity is monitored by a researcher. In a study by Núñez-Peña et al. (2014), participants with high mathematics anxiety were shown to have high levels of electrical activity in the frontal areas of the brain which controls size and distance awareness, far higher than students with low mathematics anxiety. In addition, participants were also given a magnitude comparison test. The test involves comparing pairs of dot arrays and identifying which array has the largest number of dots in each pair. The test typically takes a minute to complete, and the number of dots in an array can differ from 1 – 6 (Jay & Betenson, 2017). Participants with high mathematics anxiety had slower reaction times than those with lower mathematics anxiety. This further confirms the notion that students with higher mathematics anxiety may focus their attention on their worries and concerns rather than the maths problems presented.

Further brain activity measures to identify signs of mathematics anxiety, including MRI (Magnetic resonance imaging). MRI uses radio waves and magnetic fields, to create detailed images of the inside of an individual's body. The scan can be used on any part of the body, for mathematics anxiety the focus is on the brain, where studies have found adults with high mathematics anxiety have less activity occurring in both the frontal and parietal areas of the brain, compared to those with lower mathematics anxiety (Lyons & Beilock, 2012). In line with the rest of the literature this shows that the drop in mathematics performance is due to students focusing on their anxiety related thoughts and symptoms, rather than the maths problems at hand (Dowker et al., 2016).

That said, while physiological measures like cortisol, EEG, or MRI offer insights into the biological underpinnings of mathematics anxiety, their high cost, invasiveness, and logistical challenges make them impractical for most social science research settings. A simple mathematics anxiety rating scale is a more practical, cost-effective, non-invasive and easier to implement, reducing ethical concerns and participant resistance.Therefore the scale is a directly relevant tool for studying the psychological and behavioral dimensions of mathematics anxiety (Lyons & Beilock, 2012; Piccirilli et al., 2023; Yu, 2015).

This approach enables the researcher to focus on meaningful and scalable insights without being constrained by resource-intensive methodologies.

2.4.7. Existing ways to overcome mathematics anxiety

Synthesised evidence indicates that multi-component interventions are most successful. Programmes that combine study strategies, problem-solving techniques and emotion-regulation exercises produce moderate reductions in anxiety and concurrent gains in mathematical performance (Sammallahti et al., 2023). Reviews on technology and anxiety report that game-based and digital tools can help when they provide immediate feedback, scaffolded challenges and opportunities for repeated practice, but caution that distance learning without support may increase anxiety (Ersozlu, 2024). Meta-analytic findings also suggest that integrating games within broader educational frameworks (e.g., classroom instruction and peer collaboration) leads to more robust anxiety reductions (Dondio et al., 2023). Together, these findings support a comprehensive approach that blends cognitive, emotional and technological elements.

Most of the literature focuses on three main factors when analysing ways to reduce mathematics anxiety, the teachers, parents and students themselves.

2.4.7.1. Strategies aimed at teachers

Enhance mathematics skills of teachers and portray mathematics positively

Shabab (University of Sussex, 2025) emphasises safe-to-fail environments and adaptive difficulty in digital learning. He argues that if students can experiment, make mistakes and receive dynamic adjustments to challenge levels, they are more likely to persist and experience reduced anxiety. This aligns with psychological safety principles and supports the use of adaptive game mechanics.

Research has found that teachers presenting negative opinions on mathematics can increase student mathematics anxiety levels (Beilock, Gunderson, Ramirez, & Levine, 2010; Jackson & Leffingwell, 1999). A survey of British primary school teachers revealed that 68% of teachers lacked confidence in their ability to teach mathematics, with 81% of teachers experiencing negative psychological and physical feelings towards mathematics (E. Jackson, 2008).

Mathematics anxiety has also been found to increase when teachers place struggling students in intimidating situations, such as answering questions in front of the class. Mathematics questions may also be used as a form of punishment for bad behaviour also leading to increases in anxiety (Furner & Berman, 2003). Furthermore, a teacher telling a student that they cannot do mathematics can also increase mathematics anxiety over the long term (E. Jackson, 2008).

It has been recommended that teachers hone their own mathematics skills as well as dissipate any negative stereotypes or misconceptions about mathematics (e.g. only one way to reach the correct answer) (Woodard, 2004). Rather than on-the-spot questions in front of class that may embarrass underperforming students, alternative participation methods should be used to build their confidence (e.g. Teachers should ensure students recognize that everyone makes mistakes in mathematics, and confidence does not depend on good grades in mathematics (Geist, 2010). Additionally, teachers should collaborate with other colleagues to discuss issues surrounding mathematics anxiety (Cavanagh, 2007, p. 200; Furner & Berman, 2003).

Use real life applications

Using manipulatives (i.e. hands on learning items, such as toothpicks, blocks, coins) and other concrete materials helps students grasp abstract mathematics concepts (Plaisance, 2009). Teachers should attempt to attach context to mathematics content in a way that is applicable to the everyday lives of students, such as shopping or paying bills, with numerous studies showing this method helps students more appreciate the relevance of mathematics (Geist, 2010; Sun & Pyzdrowski, 2009).

Encourage deeper understanding

Drill and practice methods requiring rote learning and memorisation, while beneficial for gaining a foundation in arithmetic, have already been shown to increase mathematics anxiety due to students not gaining a deeper understanding needed for more advanced mathematics problems. Teachers should instead present mathematics as a tool for decision making and develop students' critical thinking abilities (Geist, 2010; Hellum-Alexander, 2010). Furthermore, when testing students, less emphasis should be placed on the speed and correctness of answers, but more on the methods of working out being used to gain a better perception of where students may be struggling (Woodard, 2004).

Adapt to different learning styles

Using different approaches to teaching helps cater to different learning styles amongst students. Rather than passively reading descriptive instructions, research shows engaging students through group or class discussions helps clarify problems to be solved. Visual and audio aids make use of multiple sensory channels and can help clarify abstract concepts (Reddy, 2008). Computer based learning in general has been known to reduce mathematics anxiety, due to easy access to resources, collaboration with online communities, controlled pace of work and instant feedback (Hellum-Alexander, 2010). Using a hands-on approach to learning such as educational games is recommended as an approach to make learning more interactive (Sun & Pyzdrowski, 2009). This is one of the motives for investigating whether computer games that teach mathematics could be a potential treatment for mathematics anxiety, and furthermore finding out which aspects of these games affect mathematics anxiety the most.

Utilise a variety of assessment types

When evaluating how well students are learning, rather than relying solely on timed tests, Cavanagh (2007) and Furner and Berman (2003) suggest accommodating varying student communication preferences by incorporating demonstrations, oral questioning, group discussions, projects, as well as learning and reflection logs. However, this does not mean dismissing timed tests, as regular practice can help students become more comfortable when working under pressure (Cavanagh, 2007).

2.4.7.2. Strategies aimed at parents

Display a positive attitude towards mathematics

Similar to teachers, parents with mathematics anxiety can pass their anxiety on to their children, not only through genetics but by displaying anxiety symptoms that make mathematics appear as something to be feared or avoided. Some studies have suggested parents should adopt methods to reduce their own anxiety about mathematics to avoid making it worse for children (Sparks, 2011). Additionally, mathematics is often associated with negative situations such as unpaid debts, tax returns and bills. Getting children involved in activities that may make use of mathematics in a positive way (e.g. sports, home repair, cooking), can help their children see the benefits of learning mathematics (Curtain-Phillips, 2001).

Monitor progress and provide support

Cavanagh (2007), found that parents who had overly high expectations of their children were more likely to increase their mathematics anxiety. Conversely Furner and Berman (2003) discovered that parents were aware of what their children were learning and had an understanding of their progress that could help reduce mathematics anxiety. In such cases, parents could spot mathematics anxiety in their children, inform their teacher, and get information about areas where their children need help the most with the aim of providing extra tuition where possible (Scarpello, 2007).

2.4.7.3. Strategies aimed at students

Practice and relax

Many studies emphasize daily practice using one's own learning style, as repetition will help students memorise and better recall any techniques for solving mathematics problems (Cavanagh, 2007; Freedman, 2010; Haralson, 2002). Techniques should be applied to make studying less stressful, such as scheduled break periods, avoiding distractions and breaking down large amounts of learning content into small chunks. Relaxation techniques such as time-outs when frustration occurs, deep breathing, and repeating positive messages and focusing on past success are also recommended as a method of reducing mathematics anxiety (Furner & Berman, 2003; Scarpello, 2007).

Ask for help to ensure understanding

Other authors found that students who only memorise content rather than understanding it will struggle to recall content if anxiety sets in. Immediately asking for help from peers, teachers or parents when needed, is a good way to gain different perspectives on the same problem and enhance understanding.

Listen to sedative music

Sedative music is known to be melodic calming music used for therapy. It comprises a steady melody with minimal alterations to the pitch or rhythm. The rhythm in particular, plays at the same speed at a resting heart rate. Most studies measure their ability to reduce stress and assess the impact of physiological and psychological outcomes, having positive results overall (de Witte et al., 2019). Several studies have confirmed listening to sedative music effectively regulates the symptoms of mathematics anxiety, including systolic blood pressure, heart rate and reducing mathematics anxiety overall (Gan et al., 2016; Haynes, 2004).

2.4.8. Identifying a model to structure this research

The final sections in this chapter, 2.4.8, 2.4.9 and 2.5, will explain methodological decisions concerning the diagram chosen to structure research findings, and the scale used to measure mathematics anxiety.

As described in section 2.4.7, strategies to overcome mathematics anxiety within the broader educational and social content have been discussed in the literature. However, as Dondio et al. (2023) identify, there is not research into the strategies that should be adopted in designing games that aim to address mathematics anxiety.The aim of this research is to fill this gap, by developing a model that identifies game design attributes that impact mathematics anxiety. Employing a model enables the factors to be displayed in a single diagram. This should be accessible to anyone conducting research in this area, but ultimately be used when designing computer games.The researcher, having examined the literature, selected the Ishikawa diagram, also known as a "Fish bone" or "cause and effect" diagram, which is widely employed in literature. This is because it is specifically designed to present the underlying causes behind a specific event. It has been used as a tool for quality control, as outlined by Ishikawa in 1985. Such models have proven valuable in determining the components and subcomponents necessary for evaluating usability.

For instance, in their work, Adikari, S. et al. (2007) introduced an Ishikawa diagram to illustrate the conceptual model of usability attributes and their measurable criteria. This diagram effectively demonstrates that usability encompasses seven distinct attributes: efficiency, functional correctness, error tolerance, learnability, memorability, flexibility, and satisfaction. Each of these usability attributes is influenced by multiple measurable aspects relevant to the system or product's usability.

Notably, the attribute of "Efficiency" can be evaluated based on the examination of three components: E1 - Task completion within the shortest possible time, E2 - User tasks devoid of misleading elements, and E3 - The absence of the need for workarounds. These components contribute to understanding and assessing the efficiency of a system or product in terms of usability.

The presented model could help in the evaluation of educational games and their impact on mathematics anxiety among university students. By adapting this model to assess the features of educational games, researchers can gain insights into how these games influence students' anxiety levels when it comes to mathematics. The inclusion of the model's original depiction by Adikari., et al. (2007) in Figure 2 further enhances the clarity and understanding of their conceptual framework.

Overall, this model serves as a valuable tool for assessing and improving the usability of various systems and products, with potential applications in educational contexts as well.

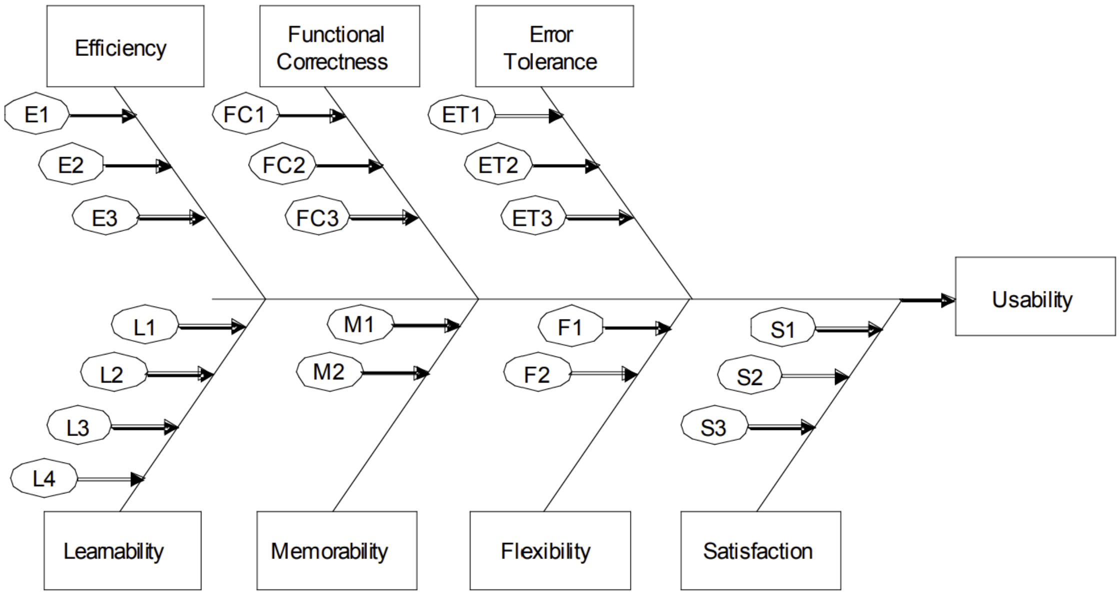

Figure 1: Conceptual usability attribute model and measurable criteria - fishbone model (from Adikari, S. et al. 2007, p. 431)

Efficiency	Functional Correctness	Error Tolerance
E1 – Task completion in minimum time	FC1 – Task completion in minimum time	ET1 – Appropriate error messaging for invalid conditions
E2 – User tasks are not misleading	FC2 – User tasks are appropriate, effective and match the user needs	ET2 – Ability to exit error conditions or unwanted states
E3 – No workarounds are needed	FC3 – User spends minimal time on "Help"	ET3 – No workarounds are needed
	Satisfaction	
	S1 – User desirability of the system and user tasks	
	S2 – User opinion about user experience	
	S3 - User opinion about frustration or confusion	
	Learnability	
	L1 – Clear visibility of current system status and a feel about what to do next	
Memorability	L2 – User tasks are not misleading	**Flexibility**
M1 – No memory recall to carry out tasks	L3 – Task completion in minimum time	F1 – Multiplicity of ways to carry out user tasks
M2 – User spends minimal time on "Help"	L4 – User spends minimal time on "Help"	F2 – User control of task performance

Figure 2: Conceptual usability attribute model and measurable criteria - table (from Adikari, et al. 2007, p. 431)

In another study, Ngamntwini and Cilliers (2019) developed a usability framework for diabetic health applications in South Africa. The framework utilised a qualitative research approach and employed a fishbone model. To create the framework, the researchers conducted a literature review and then evaluated the seven most popular free diabetic applications on the Google Play Store, refining the model based on their findings. The study concluded that health applications should prioritise ease of learning, efficiency of use, ease of recall, minimal errors, and subjective satisfaction for patients.

Similar to the usability attributes fishbone model, this model can be adapted and applied to investigate the impact of educational computer games on mathematics anxiety. This model would provide a structured framework for assessing the usability factors and effectiveness of educational games in reducing mathematics anxiety and enhancing mathematical skills.

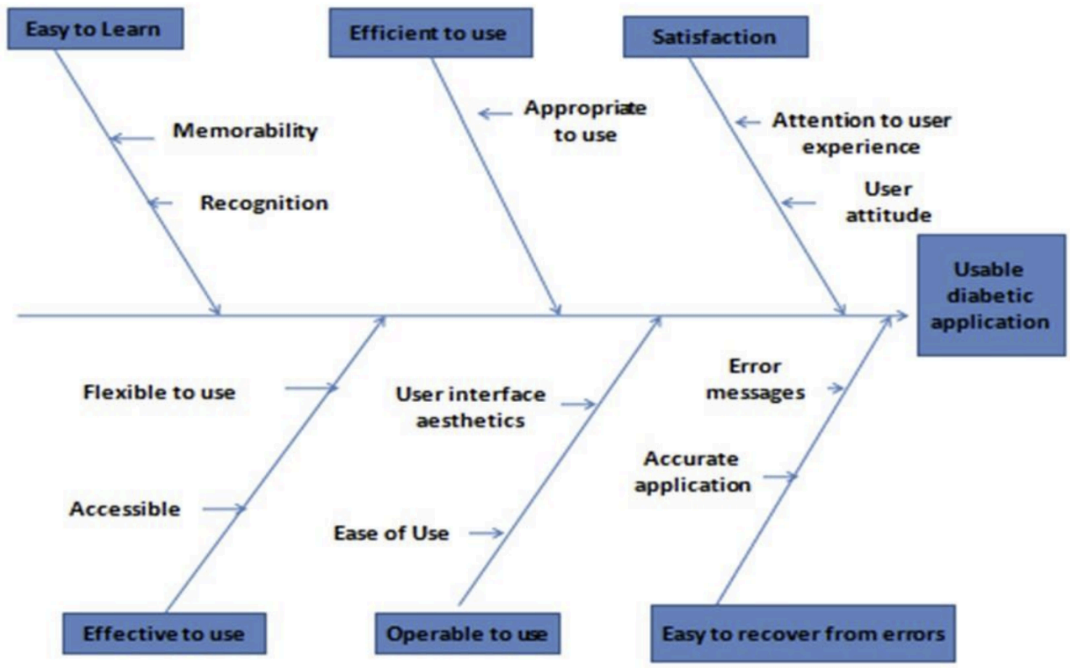

Figure 3: Usability framework for diabetic apps (Ngamntwini & Cilliers, 2019)

From the usability criteria and diabetic app examples, the fishbone model presents itself several advantages and disadvantages.

2.4.8.1. Advantages of the fish bone model

The fishbone diagram provides a structured and visual method for analysing the attributes of computer games that influence mathematics anxiety among university students. Its hierarchical organisation of causes into main and subcategories ensures comprehensive coverage of factors such as gameplay mechanics, reward systems, and cognitive challenges. The model facilitates collaborative brainstorming, making it an effective tool for educators, developers, and stakeholders to collectively identify potential issues. Its visual simplicity makes it accessible even to non-experts, and its adaptability allows for application across diverse educational contexts. By offering a clear, organised overview of contributing factors, the diagram enables users to approach the problem with clarity and systematic thinking (Ellis, 2015; Hussain & Masood, 2023; Skulmowski & Nebel, 2021; Liao et al., 2022).

2.4.8.2. Disadvantages of the fish bone model

However, the fishbone diagram has several limitations. It can oversimplify complex interrelations, that could be shown for example in a venn diagram (Kestler, 2014; Firican, 2018). This would be true particularly for psychological and sociocultural factors affecting mathematics anxiety, and the diagram lacks the capability to prioritise or quantify the impact of identified causes, limiting its utility in data-driven analysis. The time and effort required to create a detailed diagram can be substantial, especially for nuanced issues. Additionally, its complexity may lead to cognitive overload, diminishing its effectiveness (Ahmad, 2024; Tian & Li, 2020; Gündüz, 2016; Zhang et al., 2016; Zhou et al., 2020).

Despite the disadvantages of using the fishbone model, the advantages outnumber the disadvantages and similar studies focusing on anxiety traits also use the fish bone model. Therefore the research made the decision to use it in this study. This is discussed further in section 3.6.1.

2.4.8.3. Relevance of the fish bone model in pragmatic research

The fishbone diagram aligns well with a pragmatic research approach, which focuses on practical solutions to real-world problems. Pragmatism allows for diverse methods to achieve informed solutions, prioritising what works best to meet research objectives. In this study, which aims to reduce mathematics anxiety through educational game design, the fishbone diagram is used to map cause-and-effect relationships in a practical, problem-solving way (Biesta, 2010; Morgan, 2014). Originally developed for quality control (Ishikawa, 1985), it is now widely used across fields to dissect complex issues, including education (Nwobodo-Anyadiegwu et al., 2017).

The diagram supports the integration of qualitative and quantitative data, a hallmark of pragmatic research. The study used multiple methods, such as surveys and gameplay observations, and the fishbone diagram organises these findings into a coherent visual model. This model helps identify game design attributes that affect anxiety and provides actionable insights for educators and designers. It simplifies complex relationships, making it accessible to practitioners without specialised research training.

Previous research has shown the diagram's ability to convert analysis into practical recommendations, making it a useful tool for bridging theory and action (Slameto, 2016).

The key aim and objectives of this study are to identify game attributes that affect mathematics anxiety and to develop a usable model of these relationships for game designers and educators. The fishbone format directly supports these aims and objectives. Its hierarchical cause–effect structure allows the identified game attributes (e.g. gameplay mechanics, difficulty level, feedback systems, narrative context) to be categorised under thematic "bones," all connecting to the head representing "mathematics anxiety" (the effect). This not only provides a clear picture of how disparate design elements contribute to anxiety, but also highlights multiple points of intervention. Because the diagram presents causes and sub-causes visually, it can communicate complex relationships at a glance. Practitioners without specialised research training can readily grasp which aspects of a game might need adjustment to alleviate anxiety.

In summary, the fishbone diagram is a fitting choice for this study, offering a structured yet flexible approach that directly addresses real-world issues in mathematics anxiety. It integrates multiple data sources into a unified solution, making it a practical tool for improving educational game design.

2.5. Systematic literature review of mathematics anxiety scales

The aim of this systematic literature review is to identify mathematics anxiety scales used in the literature and select one to use based on their suitability for the researcher's study. It should be noted that this literature review was carried out in 2016, prior to data collection. and was later updated in 2020, however no new scales were identified that met the inclusion criteria (see section 2.3.4).

2.5.1. Systematic literature review process

Depending on the field studied, the stages of performing a systematic literature review differs in number and processes involved. In healthcare for example, (Higgins & Green, 2008) highlight four phases. These are;

- Define the search terms
- Identify databases, search engines and journals to search
- Decide on, and apply, filters for inclusion and exclusion
- Ensure that the resulting articles are representative, by repeating the filtering process

In software engineering, Keele (2007) refers to three broader phases (planning the review, conducting the review, and reporting the review). These are broken down into the thirteen more precise processes, such as specifying the research question, data synthesizing and formatting the report.

Both systematic review models are similar in terms of planning and conducting the review. However, the Keele (2007) software engineering model is more specific in procedures, as well as providing guidance for reporting the review. Repeating the filtering process to ensure articles are representative is unique to the Higgins and Green (2008) model.

For university courses in general, the Petticrew and Roberts (2006) seven stage model is a shorter, more summarized version of the longer Keele (2007) model.

Having identified existing systematic literature review processes in different fields, this review includes or excludes certain processes from each model to ensure relevance to the research objectives of the study. The process is as follows:

- Identification of the need for a review (Keele, 2007).
- Determine the type of studies that need to be located (Petticrew & Roberts, 2006)
- Decide on, and apply, filters for inclusion and exclusion (Higgins & Green, 2008).
- Define the search terms (Higgins & Green, 2008).
- Carry out a comprehensive literature search to locate those studies (Petticrew & Roberts, 2006)
- Screen the results of that search (that is, sift through the retrieved studies, deciding which ones look as if they fully meet the inclusion criteria, and thus need more detailed examination, and which do not) (Petticrew & Roberts, 2006)
- Data extraction – Collect all the information needed to meet the objectives of the review (Keele, 2007).
- Data synthesis – Summary of findings (Keele, 2007)

2.5.1.1. The need for a literature review

Despite being used extensively in the literature, one downside of the original 98-item MARS by Richardson and Suinn (1972) is that it is a lengthy paper-based assessment, taking more time for participants to complete and for the researcher to administer and score (Ashcraft & Moore, 2009). Additionally, the original 98-item MARS is no longer available for purchase, with only shorter versions made available to buy from the original author. Alternative mathematics anxiety scales are free and have high reliability and validity as well as high correlation (i.e. showing they measure the same construct) with the original MARS making them suitable for use in the study. For example, (Plake & Parker, 1982) have a 24-item

MARS (named the Revised Mathematics Anxiety Rating Scale – RMARS) with an internal consistency reliability coefficient of 0.98, and a correlation with the original MARS of 0.97.

With many different versions of the mathematics anxiety rating scale, many shorter than others, and targeted to different demographic groups. It was worth assessing the suitability of shorter mathematics anxiety scales in terms and reliability and validity for this particular study.

2.5.1.2. Types of study required

For this systematic literature review, the researcher was looking for any study that tests the mathematics anxiety scale for validity and reliability, so as to determine suitability for the researcher's study. Studies measuring mathematics anxiety involve surveys (i.e. mathematics anxiety scales) and most often randomized control trials (comparison of mathematics anxiety between a control group and experimental group). Some may have a qualitative aspect, such as interviews or observations. There may also be existing literature reviews comparing existing mathematics anxiety scales, which may help in locating related studies.

2.5.1.3. Criteria for inclusion of scales

A number of criteria were followed for the inclusion of scales in the literature review for this study.

2.5.1.4. Studies from 1972 onwards

This helps narrow down and improve the relevance of search results by filtering out studies prior to the first published mathematics anxiety scale from 1972. For example, the term "Mathematics anxiety rating scale" via Google Scholar returned 1630 results without the time-frame filter, applying the time-frame filter returned 1590 results. The results that were filtered out referenced a mathematics anxiety rating scale, however there was no validity and reliability information about the scale so could be disregarded.

2.5.1.5. English language

This is because the study was undertaken in a UK based university, where English is likely to be the most common language used for learning mathematics.

2.5.1.6. Scale must have been tested for reliability and validity

Some scales such as the FSMAS (or Fennema and Sherman Mathematics Anxiety Scale) (Fennema & Sherman, 1976) despite their prolific usage in the literature, had little to no tests for reliability or validity until more recent years, requiring development of numerous revised versions of the scales (Lim & Chapman, 2012). Using scales without reliability and validity testing could undermine the usefulness of the results.

2.5.1.7. Target of the mathematics anxiety scale should cover university students.

Certain scales are strictly aimed at certain school levels, age groups, occupations, specific nationalities and other demographics that exclude a potentially large range of university students that the study aims to assess. Thus, in line with the research aim, it would be more valid to find and use a scale either not aimed at a specific demographic, targeting university students in general, or better yet, university students in the social science field. For example, the FSMAS, as well as the MAS (Mathematics Anxiety Scale; Mahmood & Khatoon, 2011) despite their popularity in the literature were excluded from the study as they are designed for high school students.

2.5.1.8. Cover general mathematics

Certain scales are aimed at the specific subjects within the mathematics field. For example, Al-Shannaq and Leppavirta, (2020) focuses solely on electromagnetics, which may only be suitable for engineering students at the most. As this study aimed to target all students in the university who will encounter different levels of maths, this approach would require separate scales for each subject, for example mathematics in medicine is different to the mathematics used to be accountancy, for which few to no scales exist of this specificity. As such, a scale should be used that considers all subjects involving mathematics.

Table 1 includes the mathematics anxiety scales that based on the above criteria could not be included in the study. While many had been tested as valid and reliable, the shortcomings mainly came from being written in a different language or developed for a demographic that excludes university students.

Table 1:Scales not included for potential use in study

Rating Scale	**Author**	**Citations**	**Reason(s) for exclusion**
FS-MAS (Fennema-Sherman Mathematics Attitudes Subscale)	Fennema and Sherman (1976)	1099	Scale aimed at high school students
Arabic FS-MAS (shortened)	Alkhateeb (2004)	6	Written in Arabic
Sandman Mathematics Anxiety Inventory (SMAI)	Sandman (1980)	90	No validity and reliability data
Mathematics Anxiety Scale toward Teachers and Teacher Candidates (MAST)	Üldaş (2005)	N/A	Aimed at teachers Study unpublished
Mathematics Anxiety Rating Scale-India (MARS-I)	Karimi (2008)	3	Aimed at Indian nationals
Mathematics Anxiety Scale (MAS)	Mahmood and Khatoon (2011)	5	Aimed at secondary school students
Rasch Rating Scale Model.	Prieto and Delgado (2007)	8	Written in Spanish
German version of the math anxiety questionnaire (FRA)	Krinzinger et al. (2007)	8	Written in German Aimed at children
Mathematics Anxiety Questionnaire (MAQ)	Meece (1988)	26	Aimed at high school students
Electromagnetics Mathematics Anxiety Rating Scale (EMARS)	Al-Shannaq and Leppavirta (2020)	1	Aimed at electromagnetics students
Chinese MARS-R	Wu et al. (2018)	0	Written in Chinese
MARS-E	Daharnis et al. (2018)	6	Aimed at elementary school students
MARS-A Mathematics anxiety rating scale for adults	Tooke and Lindstrom (1998)	161	No measure of validity

2.5.2. Literature search terms

Literature was retrieved using Web of Science and Google Scholar and several others. Citation counts were taken from Web of Science only. Whereas Google Scholar provides a more diverse range of citations it is also prone to duplicates and missing publication dates. Web of Science contains more documents printed before the advent of the web and includes conference papers unavailable anywhere else online (De Winter, Zadpoor, & Dodou, 2014).

Further justification of databases and additional databases used

Google Scholar: Selected for its wide-ranging search capability, Google Scholar indexes a variety of academic articles, conference papers, theses, and grey literature, making it a useful tool for identifying diverse sources. Its ability to include grey literature was particularly advantageous in uncovering niche studies that may not be included in other databases.

Web of Science (WoS): WoS was chosen for its robust indexing of high-quality, peer-reviewed journals. It provides advanced filtering options, which were used to limit results by discipline, publication type, and time frame, ensuring a focused and systematic approach to the review.

Complementary databases: While other databases were initially included to enhance comprehensiveness, their final contributions to the review were limited.

- PsycINFO: Although PsycINFO was included to capture psychology-focused studies on anxiety, particularly those examining measurement scales and interventions, the search yielded very few additional relevant papers beyond what was already retrieved from Google Scholar and WoS.
- ERIC: Selected to ensure educational research, particularly on game-based learning in mathematics, was considered. However, the majority of relevant papers were already found in Google Scholar and WoS, making ERIC's contribution redundant.
- Scopus: Used to supplement WoS with a broader range of indexed journals and conference proceedings, but search results largely overlapped with those found in WoS. Additionally, Scopus's coverage of grey literature is more limited compared to Google Scholar, making it less useful for this review.

Only results from Google Scholar and Web of Science were included in the thesis because other databases yielded fewer unique papers, and the majority of their returned results overlapped with those already identified in the primary databases. Prioritising Google Scholar and Web of Science ensured a streamlined yet comprehensive review while avoiding unnecessary duplication of sources.

The keyword terms used for searching the literature are below. These are based on terms used for mathematics anxiety scales found in various journals, websites, and blogs while carrying out the general literature review. To improve the relevancy of the results, quotes were added around each search term, to ensure the search engines used every word in that specific terms in the order displayed. The number of results represent searches prior to application of any inclusion or exclusion criteria. Demonstrating how the topic of mathematics anxiety has grown over the years, results of searches from 2015 to 2020 were recorded.

Table 2: Mathematics anxiety search terms

Search terms	Results 2015/2020	
	Google Scholar	Web of Science
"Maths anxiety rating scale"	32/54	0/0
"Maths anxiety rating scale" "validity" "reliability"	6/26	0/0
"Math anxiety rating scale"	333/631	7/8
"Math anxiety rating scale" "validity" "reliability"	187/358	3/3
"Mathematics anxiety rating scale"	1630/2910	38/49
"Mathematics anxiety rating scale" "validity" "reliability"	752/1340	7/8
"MARS" "validity" "reliability"	25,400/37,200	45/87
"MARS" "validity" " reliability" "mathematics"	10,100/ 13,700	8/10
"MARS" "validity" "reliability" "mathematics" "anxiety"	2360/3770	8/9
"Mathematics anxiety scale"	773/1460	42/59
"Mathematics anxiety scale" "validity" "reliability"	430/845	9/11
"Mathematics anxiety scale"	20/1460	1/59
"Mathematics anxiety scale" "validity" " reliability"	24/845	0/11
"Math anxiety scale"	404/950	8/18
"Math anxiety scale" "validity" "reliability"	263/653	5/8
"Math anxiety questionnaire"	117/280	3/5
"Math anxiety questionnaire" "validity" "reliability"	66/159	0/0

Synonyms and related terms

For example, "math anxiety" was supplemented with "mathematics apprehension," "numerical anxiety," and "arithmetic-related stress."

Contextual variations:

Boolean operators (e.g., AND, OR) and truncation (e.g., "math* anx*") were also employed to ensure flexibility and inclusivity in retrieving studies across disciplines and varying terminologies.

2.5.3. Literature search process

The search terms devised above were applied to both Google Scholar and Web of Science. Web of Science always returned less articles than Google Scholar.

Upon each search, article titles were scanned through, if they appeared to be relevant to the research aim, then the abstract was read in detail. In terms of time frame, studies that were included dated back to 1972 from when the first mathematics anxiety scale was published. This is because older mathematics anxiety scales such as (Fennema & Sherman, 1976) are still being utilized in recent studies. Search terms began with a main key phrase e.g. “Mathematics anxiety rating scale”. Where a search term yielded too many results, or too many irrelevant results, the researcher used the more specific variation of the search term, adding the keywords “validity”, and “reliability”. This proved to be effective in refining the results. Adjusting the search term to include the keywords “validity” “reliability” returned 25,400 results, while the majority of articles were relevant, many articles were studies in medicine and other topics other than mathematics. Adding “mathematics” and ``anxiety” to the search term reduced the results to 2360 articles, while still too many links to check through, irrelevant articles were minimal, showing the topic has been well researched. It should be noted that searching using one of the alternative main key phrases such as “Mathematics anxiety scale” yielded a more manageable 20 results or less.

All Web of Science articles were examined. However, to save time and make the results easier to manage, only the first 100 links returned by a search were scanned through on Google Scholar, which is a limitation of the strategy. The second limitation is that additional databases could have been searched, which may have revealed additional scales to include.

In general, for 2015 mathematics anxiety scales had already been well researched. A search for "Mathematics anxiety rating scale" including quotes using Google Scholar revealed 1630 results and without quotes revealing 202,000 results.

In 2020, the number of results for each search term increased substantially. For Google Scholar the number of results increased by 683% on average, however this figure was mostly caused by three outlier search terms;

- "Mathematics anxiety rating scale" which as seen in the table, jumped from 20 results to 1460, a 7200% percent increase.
- "Mathematics anxiety scale" "validity" "reliability", with an increase from 24 to 845 or a 3421% increase.
- "Maths anxiety rating scale" "validity" "reliability" with an increase from 6 to 26 making it a 333% increase.

Reasons for the surge in literature for these search terms are unknown, though may be caused by frequent changes in Google's search algorithm (Meyers, 2019). Exclude these particular search terms and the results present a smaller but still significant 89% increase in literature related to those terms.

For Web of Science, the overall average increase in mathematics anxiety articles from 2015 to 2020 was 348.85%, over 300% lower than the Google Scholar database. Similar to Google Scholar there were some outliers causing the percentage change in literature results to be significantly steep. For example, the terms "Mathematics anxiety scale" the results returned 1 paper in 2015, then 59 in 2020, resulting in a 5800% increase. By removing both outliers, the average percentage of articles retrieved reduces from 348.85% to just 31.4%.

Table 3 shows a list of mathematics anxiety scales found to be reliable and valid measures of mathematics anxiety. Many scales are correlated with the original MARS by (Richardson & Suinn, 1972) (e.g. see R-MARS, A-MARS, MARS-S). Several scales measure correlation indirectly with the original MARS. For example, MARS-R Revised (Hopko, 2003) measures correlation with the older version named MARS-R (Plake & Parker, 1982), which was previously found to be highly correlated with the original (Richardson & Suinn, 1972) MARS. Other scales such as MAS-UK (Hunt, Clark-Carter, & Sheffield, 2011) measure validity and reliability without attempting to find correlation with the original MARS.

Table 3: Validity and reliability of scales to use for study

Rating Scale	Author	Items	Participants	Reliability	Validity	Citations
MARS (Mathematics Anxiety Rating Scale) (copyright restrictions).	Richardson and Suinn, (1972)	98	387 freshman and sophomore college students (University of Missouri) approximately 80% female.	Test-Retest .85 indicating good reliability (7 week time gap). Internal consistency coefficient alpha .97 Indicating excellent internal consistency.	Pearson product moment correlation coefficient -.64 ($p < .01$ indicating high MARS scores are associated with poor Mathematics performance. Three studies showing decreased Mathematics anxiety scores after different treatments.	16
MARS-R (Revised Mathematics Anxiety Rating Scale)	Plake and Parker, (1982)	24	50 upper level undergraduate and beginning graduate students in an educational statistics class (large Midwestern University).	Internal Consistency reliability coefficient (coefficient alpha) of .98. (Plake & Parker, 1982)	Correlation between MARS-R and MARS was .97.	56
sMARS (Abbreviated Mathematics Anxiety Rating Scale)	Alexander and Martray, (1989)	25	517 college students enrolled on optional psychology courses, but with majors ranging in computer science, math, history, English, education, foreign language, social work, or psychology (regional state university).	Test-Retest .746 indicating good reliability (2 week time gap) (Fleck, Sloan, Ashcraft, Slane, & Strakowski, 1998) Correlation with overall MARS scores $r = 0.96$ (very high) (Fleck et al., 1998)	Pearson product-moment correlation coefficient Correlation with original MARS $r = .96$ (Fleck et al., 1998)	66

Rating Scale	Author	Items	Participants	Reliability	Validity	Citations
MARS-R (Revised)	Hopko, (2003)	12	815 undergraduate students (419 females and 396 males).	Internal Consistency reliability coefficient LMA – Learning Mathematics Anxiety, α = .87 MEA – Mathematics Evaluation Anxiety, α= .85 LMA and MEA are highly correlated r = .72.	Correlation between MARS-R revised and original MARS-R: (Plake & Parker, 1982) r = .97, p < .001	35
MARS-S (brief version)	Suinn and Winston, (2003)	30	124 female and male Introductory Psychology students (63 women, 61 men).	Internal consistency High internal consistency: Cronbach alpha = .96 Test-retest reliability .90 (p< .001)	Correlation with original MARS (98-item) r =-.92 (p< .001) for the original testing and -.94 (p < .001) one week later. Factor analysis found similar factor loadings to other researchers. Mathematics test anxiety accounted for 59.2% of variance (Eigenvalue = 13.02) Numerical anxiety accounted for 11.1% variance (Eigenvalue = 2.44)	16
A-MAS (Abbreviated Math Anxiety Scale).	Hopko, Mahadevan, Bare, and Hunt, (2003)	9	1239 undergraduate students (729 females, 510 males). Mean age = 19.6 years (SD = 3.0 years)	Test-Retest Reliability (2 weeks) LMA – learning mathematics anxiety r = .78 (Acceptable reliability) MEA subscales r = .83 (Good reliability). AMAS r = .85 (Good reliability). Internal Consistency Cronbach alpha of 0.90	Convergent validity between LMA and MEA (r = .62) Between original MARS and AMAS (r = .85). Divergent Validity Between AMAS and other measures (r = .20 -.54). Confirmatory Factor Analysis (tests whether a model fits different samples. Goodness-of-fit indexes as follows:χ2 = 50.81 (26 df), RMSEA = .06, GFI = .95, AGFI = .92, BCFI = .96.	35

Rating Scale	Author	Items	Participants	Reliability	Validity	Citations
MAS-R	Bai, Wang, Pan, and Frey, (2009)	14	78 undergraduate students from different disciplines. All entered into entry level mathematics courses. Midwest community college. 36 males and 42 females. 64% of the sample aged between 18 and 24. 36% of samples aged over 25.	Internal consistency reliability Cronbach alpha coefficient = .91. Indicating excellent internal consistency. Parallel-item consistency (response to two of the same questions). Item-total correlation (consistency of responses between participants, those outside average are discarded.). All items measure consistently with the total scale.	Standardized path coefficients for the revised model ranged from .43 (Item 1: LMA) to .86 (Item 2: MEA). Factor structure (construct validity). Negative effect factor = .67 to .89 (46.5% total variance) Positive effect factors = .67 to .87 (20.2% total variance). The two factors explained 66.7% of the total variance. Valid instrument to measure math anxiety with both positive and negative effects. One factor (14 items) $\chi^2 = 330.01$, df = 77. Two factors (pos, neg effects). $\chi^2 = 164.54$, df = 76.Significant difference $p < .001$. Two factors fit the data significantly better than one factor model. Has excellent construct validity.	Article N/A on Web of Science
MAS-UK (Mathematics Anxiety Scale – UK)	Hunt et al., (2011)	23	1153 (554 men, 609 women). Undergraduate students at Staffordshire University, UK (post 1992).	Discriminatory power - between subjects T-test ($p< .001$). Test-Retest $r(129) = .89$ Internal Consistency reliability coefficient Cronbach alpha of 0.96. Indicating excellent internal consistency.	Construct Validity Significant negative correlation between mathematics anxiety and basic mathematics performance: $r(281) = -.40$, $p < .001$ No significant relationship between trait anxiety and mathematics performance.	4

Rating Scale	Author	Items	Participants	Reliability	Validity	Citations
SIMA	Nunez-Pena, Guilera, and Suarez-Pellicioni, (2014)	1	1st and 2nd year psychology students at the University of Barcelona (Spain). 210 women and 69 men with a mean age of 21.07 years. Previously studied social science (32.3%), science (22.9%), humanities (20.4%), technology (6.8%), or others (3.9%).	Test-Retest Estimated reliability of 0.63 (uses Wanous and Reichers (1996) approach) (7- week time gap). Could be marginally accurate given this is the lower limit of the estimate, with a higher limit of 0.90. Factor analysis .70 (adequate reliability). Intraclass correlation coefficient .81 (showing adequate test reliability.	Correlation between SIMA and sMARS r = .77 (indicating a strong positive correlation).	1

2.5.4. Summary of systematic literature review for mathematics anxiety

Several trends were identified in researching the literature involving mathematics anxiety scales. Overall, the more questions included in a scale the higher the reliability. The difference was particularly noticeable between SIMA and the original 98-item MARS scale. SIMA had an estimated test-retest reliability of 0.63 over a 7-week time gap, indicating questionable reliability. The original MARS over the same period had a test-retest reliability of 0.85, in contrast, indicating good reliability. It was difficult to compare validity due to the different measures and timescales being used for each study. However, it can be concluded that all scales to various degrees are valid measures of mathematics anxiety, whether they are correlated with already validated mathematics anxiety scales or associated factors such as basic mathematics performance. Study participants turned out to be mostly female, with female participants having higher levels of mathematics anxiety than males (Hopko et al., 2003).

In 2015, the researcher emailed the original author of the 98-item MARS scale and received the following reply:

"Sorry longer version no longer available. The short version was validated against the long version. On a college sample, correlations between the MARS-S and the longer MARS were found to be r =-.92 (p< .001) for the original testing and -.94 (p < .001) when both tests were re-administered one week later. Hence the MARS-S appears to be equivalent to the MARS" (Suinn, 2015).

The above email also mentions the validity data of the 30-item MARS-S, showing that it is just as valid as the 98-item MARS scale, hence saving administrative time while being just as suitable for research as the original MARS, therefore the MAR-S was chosen to be used for this study.

2.6. Everyday mathematics literature

Building on the discussion of mathematics anxiety, it is also important to consider how individuals encounter mathematics in everyday contexts. Previous research on everyday mathematics has attempted to identify the attributes of mathematics learning outside schools and other educational institutions. Studies such as those of de Abreu (1995); Civil, (2002), among others found four noticeable characteristics of mathematics learning taking place outside of schools amongst the general population:

- Learning mainly occurs through apprenticeship;
- Mathematics problems are contextualized;

- The person solving the problem has some level of control over the activities and strategies;
- The mathematics involved in the activity may be unseen and can possibly be ignored in attempting to solve a problem.

In Civil's (2002) study on the usage of everyday mathematics in the classroom, the author recommends not necessarily bringing everyday tasks involving maths to the classroom but attempting to implement a learning environment that reflects these four attributes of learning. A vast range of studies discover how people often solve mathematics problems error-free in conditions that they view as relevant to their everyday lives (Abreu, Bishop, & Pompeu, 1997; Lave, 1988; Masingila, 1994; Nunes, Schliemann, & Carraher, 1993; Saxe 1988). As such, the literature on everyday mathematics has been studied extensively in the past, encompassing a variety of countries and cultures (Bishop, 1988; Carraher & Schliemann, 2002). Bishop's (1988) literature review identified six types of everyday mathematics activity across numerous age groups, countries and cultures. These included counting, locating, measuring, designing, playing and explaining.

However, few studies have examined the everyday mathematics of university students, an important demographic due to high attrition rates as well as failure rates on mathematics heavy university courses (Beaubouef & Mason, 2005; Dowe, Gardner, & Oppy, 2007). Furthermore, concerns from employers about STEM (Science, Technology, Engineering, Mathematics) skills shortages in the workplace has since led to numerous interventions encouraging students to enrol on courses involving mathematics (Caprile, Palmén, Sanz, & Dente, 2015; Wakeham, 2016).

One of the game elements that participants preferred in Study 1 (see Study 1 results) was a relatable story, referring specifically to the Giving Change game. Giving change applies arithmetic to an activity student's take part in in everyday life, i.e. handling money and shopping. Thus the purpose of this research is to discover how students use mathematics in their everyday lives. This data can be used as a basis to create a game encompassing everyday activities that participants can identify with, as well as incorporating the preferred usability preferences that engage participants that encourage them to play again.

It was anticipated that the varying financial responsibilities amongst different age groups, full time, part-time students and distance learning students, as well as students who live at home or stay in student accommodation, might affect how students use mathematics everyday outside of their course. For example, students living at home with their parents have been found to have different spending habits to students living off campus e.g. off campus students have extra utility, food, and housing bills (Duy, 2013). Full time students are known to have lower daily expenditure than part time students (Pollard et al., 2013), while distance learners may have alternative experiences dealing with numbers due to not having to attend the on-campus university at all. Mature students are more likely to have family or caring responsibilities and female students are more likely to follow a budget planner than male students. This may affect how these groups interact with numbers on a daily basis, and (McVitty & Morris, 2012; Stollak, Vandenberg, Steiner, & Richards, 2011).

2.7. Games used in mathematics anxiety studies

Evidence for the efficacy of games alone remains tentative. A recent meta-analysis of digital game interventions concluded that overall reductions in mathematics anxiety are small and not statistically significant, calling for further research to identify which game mechanics, such as feedback style or collaborative features, best reduce anxiety (Dondio et al., 2023). Until such evidence accumulates, games should be viewed as promising components of broader, multi-layered interventions rather than stand-alone solutions.

Table 5 shows that with the few studies researching the relationship between computer games and mathematics anxiety, there is little agreement on particular games to use for mathematics anxiety studies. The games are often custom made for the study itself and involve a wide range of mathematics topics and on different platforms ranging from desktop, tablets, Xbox Kinect and others (Hung, Huang, & Hwang, 2014; Isbister, Karlesky, Frye, & Rao, 2012; Jansen et al., 2013; Verkijika & De Wet, 2015). Two mathematics anxiety scales were identified, the Fennema and Sherman Mathematics Attitude Scales, FS-MAS (Hung et al., 2014; Verkijika & De Wet, 2015), and the second was a variation of the MASC (Math Anxiety Scale for Children) aimed at the Dutch education system (MASC-NL). One study in particular, used a neuro-feedback headset to monitor mathematics anxiety levels (Verkijika & De Wet, 2015). All studies where mathematics anxiety was measured used an entirely quantitative methodology. Participants were children, the oldest age being 16. Studies were conducted worldwide from South Africa, the U.S., Netherlands, to Taiwan.

Hung et al (2014), found no significant difference in mathematics anxiety between students using an eBook-based game and those not using a game for study. However, the Verkijika and De Wet (2015) BCI game and the Jansen et al., (2013) browser-based game reduced mathematics anxiety to varying degrees. Jansen et al., 2013 and Hung et al., 2014 also measured mathematics performance, both finding improvements in learning. However, as the studies are aimed at 9-16 year old children, it is unclear whether computer games will have similar impact on the university level students or adults in general.

2.7.1. Game search methodology

In 2015, when searching for games that have been used in mathematics anxiety studies the literature was found to be so scarce that few criteria were considered to return the maximum results, prioritising recall.

2.7.1.1. Should not include board games

Though ultimately any search terms had to exclude board games, as the researchers own study focuses on computer games. For many searches, the “-board” term was used to filter out journals covering board game topics.

2.7.1.2. Games used in previous mathematics anxiety studies

The aim of this literature review was to determine the range of games available that have been used as a potential treatment for mathematics anxiety in students: therefore a systematic review was not required. Many studies involving mathematics games simply refer to mathematics anxiety as a factor affecting maths performance, but do not investigate whether said games actually have an impact on mathematics anxiety. As there is known to be a negative correlation between mathematics anxiety and performance, it is important to assess which types of games and their attributes affect mathematics anxiety. As in the researcher’s own study, mathematics anxiety should ideally be measured using a mathematics anxiety scale for easier comparison, or at least gather participant opinions on what kind of impact the games have on their anxiety levels.

Similar to the keywords used for searching for mathematics anxiety scales, the three main spelling variations were used for searching for mathematics anxiety, “mathematics anxiety” (universal), “math anxiety” (US) “maths anxiety” (UK). For the search for games, three variations for search terms were used. In line with game types previously in the literature these involved computer games, console games, and video games. Browser games were excluded as a search term as several initial test searches revealed very few to zero search results in Google Scholar. Given that Web of Science produces less than 5% the number of papers than Google Scholar overall, it is unlikely that any results would have been returned from Web of Science, this was the same for the term “VR games”.

Table 4: Literature search terms for games used in mathematics anxiety studies

		Results	
		Google Scholar	Web of Science
1	“Mathematics anxiety” ”computer games”	197	0
1.1	“Mathematics anxiety” ”computer game”	234	0
1.2	“Math anxiety” ”computer games”	632	2
1.3	“Math anxiety” ”computer game”	355	0
1.4	“Maths anxiety” ”computer games”	52	0
1.5	“Maths anxiety” ”computer game”	31	0
2	“Mathematics anxiety” “console games”	5	0
2.1	“Mathematics anxiety” “console game”	1	0
2.2	“Math anxiety” “console game”	1	0
2.3	“Math anxiety” “console games”	7	0
2.4	“Maths anxiety” ”console game”	31	0
2.5	“Maths anxiety” ”computer game”	52	0
2.6	“Maths anxiety” ”console game”	0	0
2.7	“Maths anxiety” ”console games”	1	0
3	“Mathematics anxiety” “video games”	355	1
3.1	“Mathematics anxiety” “video game”	235	2
3.2	“Math anxiety” “video games”	745	1
3.3	“Math anxiety” “video game”	467	1
3.4	“Maths anxiety” “video games”	35	0
3.5	“Maths anxiety” “video games”	19	0

The two search terms returning the largest number of results were “Math anxiety”, “Video games” and “Math anxiety” “computer games” in Google Scholar. Both search terms retrieved the articles shown in Table 5 overleaf. Both terms in Web of Science only returned one or two results. While these articles made reference to mathematics anxiety and computer games, they did not test games as a potential treatment of mathematics anxiety.

Furthermore, studies excluded were those making reference to mathematics anxiety but not measuring it. The results of the literature search are in Table 5. In summary, the search revealed significant variation in study populations, game types, and methodologies, limiting their applicability to this thesis. Only one study (Novak & Tassell, 2015) was conducted at the educational level of the target population. The studies used different games, with no consistent design or platform, making it difficult to determine an optimal choice. Findings on mathematics anxiety reduction were mixed, with some studies reporting a decrease while others found no effect. Additionally, variations in research designs and measurement tools further complicated comparisons. Due to this inconsistency, the existing literature does not provide clear guidance on selecting a specific game for this research.

Table 5: Games used in mathematics anxiety studies

Author	Study population	Game used	Platform	Result	Methods
Verkijika & De Wet, (2015)	Sample of 36 9-16 year olds (average age: 14.06 years old). Majority participants female (52.8%).	Math Mind	BCI headset with laptop	Mathematics anxiety reduced as result of game	Convenience sampling used to recruit participants. Participants completed a quantitative pre-test questionnaire capturing demographic information and math anxiety levels using FS-MAS. Short term, within subjects, longitudinal research approach used, participants completing two sessions over two separate days. Each session lasted between 1 and 2 hours (depending on participants' tiredness), involving 2 levels of varying difficulty. Mathematics anxiety is measured while the game is played using BCI neuro-feedback.
Isbister et al. (2012)	No population used, but game aimed at middle school children	Scoop	Xbox Kinect	N/A	Description of game and research behind the design.
Castellar et al. (2014)	Eighty-eight second graders (7 – 8 year olds) – Belgian students.	Monkey Tales	PC – Steam game.	No significant difference.	Quantitative study. Participants are randomly assigned to three groups: a gaming group, a paper exercises group, and a control group. Gaming group were instructed to play the entire educational game Monkey Tales in three weeks. Paper exercise group instructed to complete a set of maths drill exercises in the same period, equivalent work load basic and difficulty to Monkey Tales. The control group did not receive any assignment. Children were tested at two points over a three-week period: before (Pretest) and after (Posttest).

Author	Study population	Game used	Platform	Result	Methods
Jansen et al., (2013)	252 children (grade 3-6) 8-13 year olds from two primary schools (207 participated, others excluded due to absence/non-completion on some tests). 62% at risk of falling behind in education in large school, 31% in small school.	Math garden	Browser based mini-game	Mathematics anxiety reduced as result of game	Quantitative pretest/post-test measuring perceived competence, mathematics anxiety, and mathematics performance (pencil and paper administered in groups). 11.1 between tests, 5 week gap between game and post-test. All participants followed a regular math course. The experimental group used Math Garden (all over 6 weeks) Playing frequency recorded and sent to teachers twice. Mathematics Anxiety measured using MASC (Math Anxiety Scale for Children - 22 items). Questions edited as MASC-NL (23 items) to suit Dutch school system. Tempo Test Automatiseren (TTA) used for math competence. "Cognitive Competence", "Social Competence", and "General Self-worth" scales from Perceived Competence Scale for Children (PCSC) used for measuring perceived mathematics competence.
Hung et al., (2014)	69 5th graders 10-11-year olds. 36 male and 33 males.	Multiple games used including: Awareness of line symmetry figure-related buildings in life Knowing axis of symmetry and counting axis of symmetry	Android operating system on laptop	No difference in mathematics anxiety.	Quantitative pre-test and pro-test quasi-experiment. 3 methods of learning tested – digital game-based learning approach on e-books technology-enhanced learning approach on e-books and traditional instruction (control group). Each had 23 participants. FSMAS used to measure mathematics anxiety, self-efficacy, and learning motivation.

Author	Study population	Game used	Platform	Result	Methods
		Knowing point of symmetry, side of symmetry, and angle of symmetry Drawing line symmetry figures Activities for knowing point of symmetry, side of symmetry, and angle of symmetry			
Huang et al., (2014)	56 Grade 2 primary school students from southern Taiwan	Lessons about addition and subtraction in the format of a virtual store.	Tablet PC	Reported reduction in mathematics anxiety. Learning quality improved.	Quantitative pre-test/post test questionnaire and edited version the Alexander and Martray A-MARS (1989) Qualitative interviews to seek deeper meaning in the findings. 6 week long data collection process with two 40 minute lessons in addition and subtraction each week. Experimental group played the game. Control group simply had lessons.
Novak and Tassell (2015)	30 undergraduate students from the Commonwealth of Kentucky (18-24 years old, 28) females, 2 males) 10	Two games selected: Unreal Tournament 2004, and Angry Birds chosen as low stress, non AVG properties.	Video game, no console specified.	Drop in mathematics anxiety from Action game (Unreal tournament) for Non	Quantitative questionnaires – Pre-test, post-test: The Fennema–Sherman Mathematics Anxiety and Confidence in Learning Mathematics scales was used (Fennema & Sherman, 1976). 2 intervention groups, AVG (Action Video Game) and Non AVG players. 10 hours video game practice, time scale for study not specified.

Author	Study population	Game used	Platform	Result	Methods
	students majored in communication disorders, psychology, or music education			action game (anxiety slightly increased. Non-significant difference overall.	

2.8. Summary of literature review

Educational games were found to be an effective learning method for a wide range of purposes, with most studies targeted towards children and adolescents. The causes and symptoms of mathematics anxiety are numerous and can lead observers to mistake it for other forms of anxiety, in particular statistics anxiety and even general anxiety. However, there are features which are distinctive to these different types of anxiety. Existing ways of overcoming mathematics anxiety have been well researched, with interventions recommended for teachers and parents as well as students themselves. However, there are currently no specific guidelines for designing digital games to overcome mathematics anxiety

The most prominent finding from the literature review is that there are so few studies researching the effect of educational computer games on mathematics anxiety, and even fewer those involving adults as their participants. There have, however, been many studies observing mathematics anxiety and a variety of scales suitable for different demographics; the review identifying nine mathematics anxiety scales that met the inclusion criteria for use in the researcher's study. Ultimately, the MARS-S (brief version) was chosen due to its high reliability and validity, reduced number of questions, and availability compared to the original 98-item MARS.

It should be noted that the literature search was carried out during the course of the PhD. This work started in 2014 and although there have been updates to this chapter, the review is not exhaustive and there may be additional literature, scales and games available for use in future studies.

3. Methodological approach

3.1. Methodology introduction

The methodology chapter explains the reasoning behind the pragmatic research philosophy for data collection and analysis; the research design for studies 1, 2, 3 and 4; and the introduction of new tools to be used for Study 4. There will be discussion on the participants used for the study collaboration with MASH (Mathematics and Statistics Help) and assistance with participant recruitment through their services. The tools and methods for data collection, including the demographic questionnaire, mathematics anxiety scale, games to be used, and the adoption of observation methods and interviews as data collection methods will be reviewed.

3.2. Research philosophy

The research philosophy is an important aspect of any study as it informs the overall approach to the research study. Thornhill et al. (2009) defined it as "a belief about the way in which data about a phenomenon should be gathered, analyzed, and used." This section aims to explain the research philosophy adopted for this study and its advantages over other philosophies.

3.2.1. Positivism

The literature review found that most research on the impact of different treatments on mathematics anxiety used a positivist approach. Positivism is characterised by a realist ontology and an empiricist epistemology, which assumes a stable reality that can be observed and measured (Pope & Mays, 2020).

Positivism has been defined as “a system that confines itself to the data of experience and excludes a priori or metaphysical speculations." (Bryant, 1985, p. 3). It asserts that the only valid knowledge is that which can be observed and measured, and that scientific inquiry should be objective and value-free.

Positivism canbe considered an objectivist research perspective. Positivism, as a research perspective, emphasises the objective and scientific study of phenomena through empirical observation, data collection, and the application of the scientific method. It seeks to uncover general laws and causal relationships through rigorous empirical investigation. Positivists aim to eliminate subjective bias and personal interpretations, striving for objectivity in their research.

3.2.2. Interpretivism and its relationship to subjectivism

Positivism and has been contrasted both with interpretivism and subjectivism (University of Nottingham, n.d.). This section will define and contrast these two approaches.

In contrast, according to

Interpretivism arose in contrast to positivism, grounded in the view that social reality is fundamentally different from the objective natural world. Rooted in the hermeneutic and phenomenological traditions (and typified by Weber's concept of *verstehen*), interpretivism emphasizes understanding the meanings that individuals attach to social phenomena. As Chowdhury (2014) notes, interpretivist approaches hold that "people's knowledge of reality is a social construction by human actors". In other words, interpretivists reject the notion of a single, value-free truth; instead they see multiple, context-dependent realities. Researchers adopting an interpretivist stance seek to "get into the head of the subjects being studied" to interpret how those subjects make sense of their world (Guba & Lincoln, 1989). This involves focusing on participants' perspectives, motives and cultural meanings rather than imposing external hypotheses or statistics.

Ontologically, interpretivism assumes a relativist view of reality (many socially constructed worlds) and an epistemology that is inherently subjectivist. For example, Guba and Lincoln (1989) explain that the interpretivist paradigm's central task is to understand "the subjective world of human experience". In practice this means that the researcher does not stand apart from the data, but co-constructs meaning together with participants. According to one interpretivist account, the paradigm "assumes a subjectivist epistemology", the researcher recognises that knowledge arises through their own thought processes and interactions with participants. In this view, data are gathered in natural settings (through interviews, observations, documents, etc.) and interpreted qualitatively; theory is then built inductively from the data rather than tested against it. In sum, interpretivism holds that all inquiry is value-laden: the researcher's own background and the participants' viewpoints shape the research, so meaning must be interpreted within its context (Chowdhury, 2014)

Interpretivism is closely related to subjectivism in that both reject an objective, observer-independent reality. However, interpretivism is a broader paradigm: it embodies a subjectivist epistemology but insists on the systematic interpretation of meaning within social contexts. Fiske and Taylor (2013) define subjectivism as "a philosophical approach that emphasises the role of the individual in shaping reality. Subjectivists believe that knowledge and truth are constructed by individuals based on their unique experiences and interpretations of the world, and that there are no objective standards for truth". In the pure subjectivist view, an object has no inherent meaning – instead, "meaning is imposed on the object by the subject" with no necessary interplay between person and world. Interpretivism shares the subjectivist insight that knowledge depends on perspective, but it goes further by emphasising how meanings are negotiated through social interaction. Rather than treating each individual's viewpoint as a disconnected reality, interpretivists assume that meanings are co-created: people give sense to phenomena through language, culture and community. In this sense, interpretivism aligns with social constructivism. One researcher notes that the "constructivist-interpretivist" paradigm assumes multiple realities and a "subjectivist epistemology where the knower and respondent co-create understandings" (Guba & Lincoln, 1989) . Thus, although interpretivism fundamentally acknowledges subjectivity, it does so within a framework of mutual interpretation and context. In practice, this means interpretivist research does not merely report individuals' internal beliefs (as a strict subjectivism might) but interprets how those beliefs arise and make sense within the social world.

Overall, the interpretivist philosophy contrasts with positivism and pragmatism by prioritising meaning over measurement. Interpretivism posits that human beings are not passive objects of study, but agents who actively construct reality. Researchers adopting this approach therefore use qualitative, often idiographic methods, seeking depth of understanding. While aligned with a subjectivist view of knowledge, interpretivism's emphasis on context, dialogue and social construction marks it as distinct: it treats subjective meaning as the data of interest, but insists that understanding those meanings requires careful interpretation of participants' cultural and situational worldviews (Guba & Lincoln, 1989; Crotty, 1998).

3.2.3. Data collection methods representing positivism and subjectivism

Several data collection methods in the study align with positivism and subjectivism:

3.2.3.1. Pre-game and post-game mathematics anxiety assessments (MARS)

This data collection method aligns more with positivism. By employing a standardised scale like the Mathematics Anxiety Rating scale (MARS), the study aims to objectively measure and quantify mathematics anxiety levels. The focus is on empirical observation and the application of a scientific method to gather data that can contribute to objective analysis and generalisable findings.

3.2.3.1.1. Justification for Measurement Tools and Pre/Post Design

The shortened Mathematics Anxiety Rating Scale (MARS-30) was selected because it has demonstrated excellent reliability for adult and university populations (Suinn & Winston, 2003; Hopko, 2003). Its brevity reduces participant fatigue while maintaining strong psychometric validity ($\alpha = .96$), making it suitable for repeated measurement within experimental or quasi-experimental designs. Using the same measure before and after the intervention follows common practice in anxiety-reduction research (Hembree, 1990) and enables direct comparison of individual change over time. This decision therefore balances methodological rigour with practical feasibility for student participants.

3.2.3.2. Qualitative interviews

Qualitative interviews align with subjectivism. Through these interviews, the study seeks to understand the individual experiences, interpretations, and perspectives of users regarding mathematics anxiety and the impact of educational computer games. The emphasis is on capturing the unique insights and subjective accounts of participants, acknowledging the role of personal experiences in shaping reality.

3.2.3.3. Demographic questionnaire

The demographic questionnaire aligns more with positivism. It collects objective data about participants' demographic characteristics, such as age, gender, and educational background. This data can be analysed objectively and used to identify potential patterns or correlations with mathematics anxiety, in line with positivist principles.

3.2.3.4. Eye tracking

Eye tracking can be seen as correlating with both positivism and subjectivism. From a positivist perspective, eye tracking provides objective and measurable data on participants' eye movements while playing the game, enabling an empirical analysis of attention patterns. However, eye tracking can also offer subjective insights by capturing individual variations in visual attention and highlighting the subjective experiences of users (Komogortsev, et al., 2010).

3.2.3.5. Think-aloud protocol

Participants verbalised their thoughts while interacting with the games, providing insights into their cognitive processes and emotional responses. This tool was essential for linking behavioural observations with underlying thought patterns.

3.2.3.6. Diary studies

Diary studies align with subjectivism. By allowing users to track and comment on their anxiety levels as they play the game, the study aims to capture subjective interpretations and experiences. The focus is on understanding the individual's unique perspective and subjective fluctuations in anxiety levels throughout the gameplay experience.

In summary, the data collection methods in the study on educational computer games and mathematics anxiety demonstrate a combination of positivist and subjectivist approaches. While some methods prioritize objectivity, standardization, and empirical observation (positivism), others emphasize the individual's experiences, interpretations, and subjective accounts (subjectivism). This integration of perspectives allows for a comprehensive understanding of the phenomenon under investigation.

3.2.4. Analysis methods representing positivism and subjectivism

3.2.4.1. Quantitative analysis

Anxiety scale scores and everyday maths survey data were analysed using descriptive statistics (e.g., means, percentages) and inferential statistics (e.g., Wilcoxon, multiple regression) to identify patterns and test hypotheses.

3.2.4.2. Qualitative analysis

Interview transcripts and think-aloud data were analysed thematically to identify common experiences and insights related to gameplay and anxiety reduction. This interpretative approach aligns with pragmatism's recognition of subjective experiences as valuable data.

3.2.4.3. Integrated analysis

Quantitative and qualitative findings were triangulated to provide a holistic view of the data. This concurrent analysis approach aligns with the mixed-methods design, ensuring that the strengths of each method complement the other.

3.2.4.4. Justification of methodological approach

Combining quantitative and qualitative analyses reflects a pragmatic mixed-methods stance (Creswell & Plano Clark, 2017). Quantitative tests such as paired *t*-tests provide statistical evidence of change, while thematic analysis of qualitative data offers contextual understanding of participants' experiences. This integration follows established guidance in educational technology research advocating methodological pluralism to capture both outcome and process (Johnson & Onwuegbuzie, 2004; Drachen et al., 2018). The dual-method approach therefore enhances validity through triangulation and complements the study's pragmatic epistemology.

3.3. Applying both philosophies

To study the impact of educational computer games on mathematics anxiety, it is necessary to consider both positivism and subjectivism. A positivist approach involves the use of quantitative data to measure mathematics anxiety objectively, as argued by Fennema and Sherman (1976), Hopko et al. (2003), Hunt et al. (2011), and Suinn and Winston (2003). However, this approach alone is insufficient for identifying the elements of a game that affect the participant's mathematics anxiety, which requires a qualitative analysis of the participant's opinions and behaviors. Such an approach is mainly inductive and focuses on social perspectives, as noted by Crotty (1998). Therefore, a mixed-methods approach, combining both positivism and subjectivism, is more appropriate for this study. This approach is known as pragmatism in mixed methods literature, as outlined by Morgan, D. L. (2007).

3.4. Pragmatism

Pragmatic research philosophy emphasises the practicality and usefulness of research outcomes in real-world situations. It combines the strengths of positivist and interpretivist research paradigms, and emphasises the importance of mixed methods to achieve a comprehensive understanding of the research problem. Pragmatic researchers believe that research should not only seek to explain phenomena but also to address practical problems and bring about social change (Morgan, D. L., 2007).

A pragmatic research philosophy offers several advantages over other philosophies for a study on educational computer games. Firstly, it allows for a problem-oriented approach that focuses on practical solutions to real-world problems. Secondly, it recognises the importance of integrating different perspectives and knowledge sources in research. Thirdly, it acknowledges the importance of context and situational factors in research. Finally, it emphasises the importance of research findings that can be applied in practice. In contrast, other philosophies may not provide a holistic or practical understanding of the effectiveness of educational computer games.

3.5. Using pragmatism for this research

This study follows a more pragmatic knowledge claim, focusing more on the research problem than the methods adopted (Rossman & Wilson, 1985). The researcher can select approaches from both quantitative and qualitative methods to meet the needs and purpose of the research (Murphy, 1990). In such cases, triangulation occurs (Thurmond, 2001), where data is collected from different sources and analysed to provide a more comprehensive understanding of the phenomenon under investigation. In this study, a mixed-methods approach, including quantitative methods such as mathematics anxiety scales and eye tracking, and qualitative methods such as interviews and observations, is used to gain a deeper understanding of the effectiveness of educational computer games on mathematics anxiety.

Pragmatism supports methodological flexibility and the combination of quantitative and qualitative evidence to answer applied research questions (Creswell, 2014), which underpins the mixed-methods design adopted in this thesis.

3.5.1. Pragmatic research and fishbone model

3.5.1.1. The fishbone model

Section 2.4.8 outlined the rationale for using a model, and introduced the Fishbone model, giving examples of its applications and identifying its advantages and disadvantages. The Fishbone model, also known as the Ishikawa or cause-and-effect diagram, was developed by Kaoru Ishikawa in the 1960s as a tool for quality control in industrial processes. The model is a visual representation that helps to systematically identify and analyse the potential causes of a specific problem, depicted as the "head" of the fish, with the causes extending as "bones" along the spine of the fish (Ishikawa, 1990). This method is particularly effective for uncovering root causes of complex issues and organising them into categories for more in-depth analysis.

The Fishbone model works by first clearly defining the problem at the "head" of the fish. The main categories of potential causes are then identified, usually including factors such as people, methods, materials, equipment, environment, and measurement. Each of these main categories branches out into more specific causes, creating a comprehensive diagram that visually maps out the relationships between different factors and how they contribute to the overall problem (Tague, 2005).

3.5.1.2. Use of the fishbone model

In this research, the Fishbone model was utilised to analyse the various factors contributing to mathematics anxiety among university students when using educational computer games. The Fishbone model is particularly effective in identifying, organising, and displaying the potential causes of a specific problem, which in this case is mathematics anxiety.

The decision to use the Fishbone model over other frameworks stems from its structured yet flexible approach. Unlike other models that may focus on singular or linear causations, the Fishbone model allows for the consideration of multiple contributing factors and their interrelationships in a comprehensive manner (Tague, 2005). This holistic view is crucial when dealing with complex issues like mathematics anxiety, which can be influenced by a myriad of factors including personal, educational, and environmental elements.

3.5.1.3. Advantages over other models

The Fishbone model's ability to categorise causes into major categories such as environment, teaching methods, personal beliefs, and technology usage allows for a thorough examination of all possible contributors to mathematics anxiety (Ishikawa, 1990). This contrasts with models like the linear regression model, which may not fully capture the multidimensional nature of the problem.

The visual nature of the fishbone diagram makes it easier to communicate findings and relationships between different factors. This is particularly useful in educational games design where stakeholder engagement and clear communication may be essential (Anderson & Fagerhaug, 2000).

The model is flexible and can be adapted to various contexts and types of data, whether qualitative or quantitative. This adaptability makes it superior to more rigid models such as structural equation modelling (SEM), which requires specific data types and complex statistical assumptions (Schumacker & Lomax, 2016).

The fishbone model is inherently designed to facilitate problem-solving by pinpointing root causes rather than just symptoms. This is particularly useful in developing targeted interventions to reduce mathematics anxiety (Bicheno & Holweg, 2009).

The fishbone diagram is relevant within the context of the pragmatic research approach.

Step-by-step problem understanding

The pragmatic research approach places emphasis on directing attention towards the research problem (Rossman & Wilson, 1985). The fishbone diagram aligns with this notion by aiding researchers in breaking down the problem into more manageable components. It categorises possible factors causing the problem, such as technology, teaching methods, psychology, and individual differences.

Incorporating diverse perspectives

The Fishbone diagram permits researchers to amalgamate ideas from various domains, aligning with the use of mixed-methods (Murphy, 1990). It functions as a platform where experts from diverse fields, including education, psychology, and technology, can contribute insights. This collaborative aspect is particularly advantageous in the study of educational computer games.

Contextually aware research

The practical research philosophy underscores the importance of research that aligns with practicality and the real world (Rossman & Wilson, 1985). The Fishbone diagram aids researchers in identifying factors specific to the research context. It assists in dissecting the distinct factors that could influence the effectiveness of educational computer games in mitigating math anxiety in different situations..

Practical implications

The pragmatic research approach aims to yield practical outcomes (Rossman & Wilson, 1985). The Fishbone diagram aids researchers in identifying potential solutions to address the research problem. By analysing interconnected factors, researchers can propose practical interventions that are likely to be beneficial in real-world scenarios.

Overall, a pragmatic research philosophy is advantageous for a study on educational computer games as it allows for a problem-oriented approach, integration of different perspectives and knowledge sources, context-sensitive research, and practical applications.

3.6. Research design

The processes involved for each stage of data collection and study are described below.

As seen in the research design diagrams (see Figure 19A 'Research design',) an exploratory Study 1 was conducted to determine which game would be most suitable for Study 3.Since Study 1 identified the value of using everyday scenarios in maths anxiety games, Study 2 focused on identifying the ways in which people used maths in everyday life. Study 3 was conducted with the chosen game, which then informed the data collection and analysis for Study 4. It should be noted that the mathematics anxiety scale was not used for Study 1 as the sole purpose was to test the usability equipment in the iLab and games selected for the study. However, it was adopted for Study 3 to identify any issues in terms of understanding of the scale participants may have before and after playing the game, from which there was found to be none. Figure 3.5 shows the overall design of the whole research project and the contribution of each study to the final results

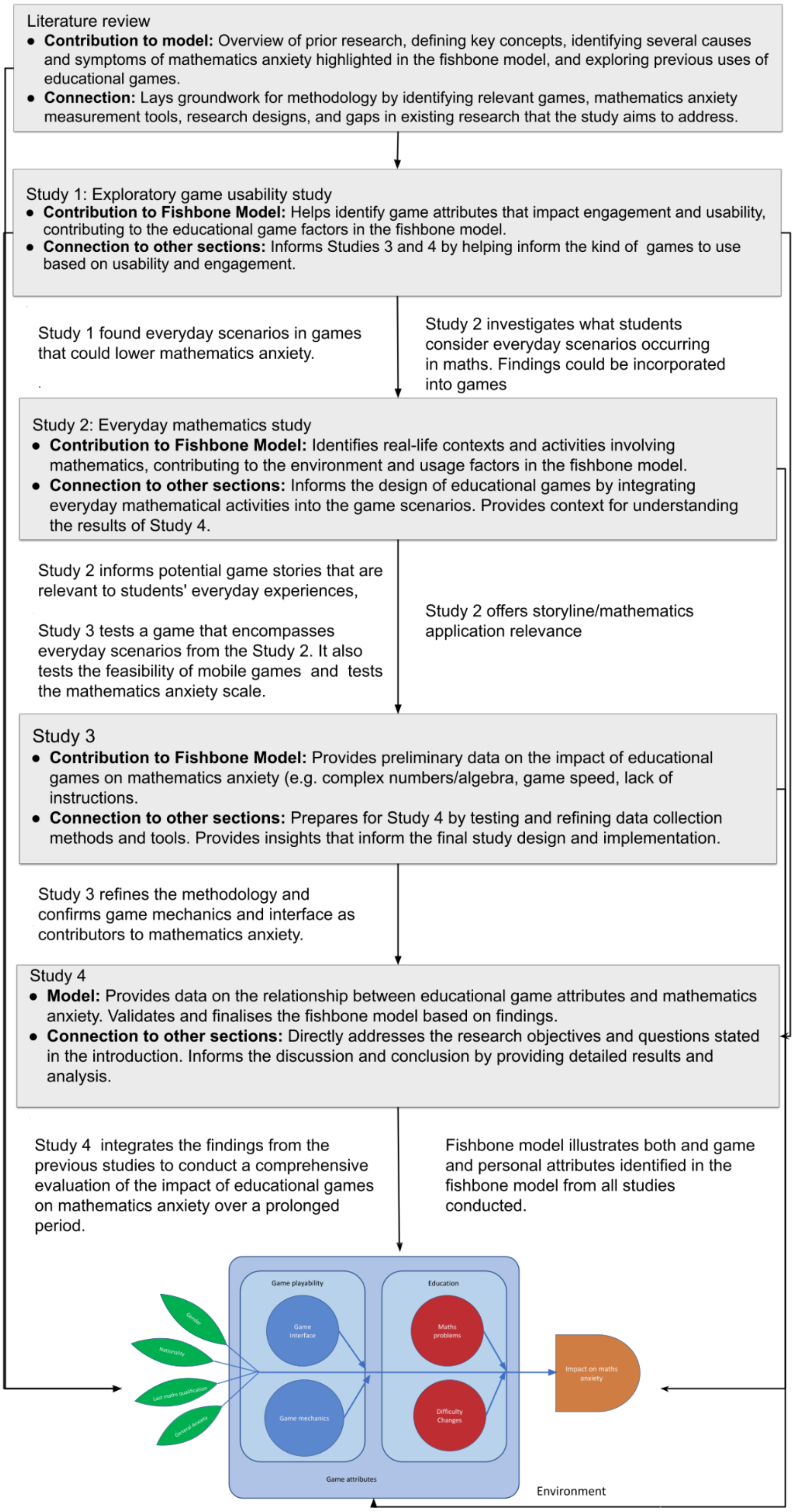

Figure 3.5: Research design

3.7. Participants for mixed methods

In this section, we will explore the diverse composition of participants across the four studies examining the influence of educational computer games on mathematics anxiety. The participant selection process was purposeful and convenient, encompassing a variety of academic levels, primarily comprising PhD students but also including master's and bachelor's students. This varied participant pool aligns with the objective of gaining a comprehensive understanding of the experiences and perspectives of students at different stages of their academic journey.

Participants are discussed here because they address methodological considerations that apply to both Study 3 and Study 4. They establish the rationale behind participant selection, measurement tools, and data collection methods, which were tested and refined in Study 3 before being applied in Study 4. Additionally, the discussion on self-reporting challenges, ethical considerations, and the comparison of anxiety scales ensures methodological robustness before full-scale implementation.

Diversity in participant backgrounds

The study deliberately encompassed participants from diverse academic levels within the university environment. This inclusion allowed for the capture of a wider range of experiences related to mathematics anxiety. While the majority of participants were PhD students, it is important to note that the intent was not to create a statistically representative sample. Recruiting PhD students was more feasible due to their proximity; they were fellow PhD students at the same university as the researcher. This proximity eased recruitment efforts and ensured a relatively larger representation of this group.

Instead, the aim was to provide a nuanced exploration of how mathematics anxiety manifests among students with varying levels of academic involvement.

Recognising the dominance of PhD students

It is important to underscore that the sample composition, dominated by PhD students, reflects convenience sampling rather than a representative cross-section of the wider university community. While recruiting doctoral students enabled an in-depth exploration of mathematics anxiety in highly specialised academic contexts, it also limits the generalisability of the results. Future studies should aim for more balanced recruitment, including a greater proportion of undergraduate and taught postgraduate participants, to better capture the range of mathematics anxiety experiences across the student body.

The predominance of PhD students in the study can be attributed to their distinctive position within academia. They often encounter mathematics in more intricate and specialised contexts, leading to unique challenges and anxieties. By focusing primarily on this group, deeper insights were sought into their experiences and the potential implications for their academic and professional development.

Implications for PhD students

It is crucial to explicitly address the implications of the findings for PhD students. PhD students represent a pivotal subset of university students, and comprehending their mathematics anxiety can contribute to more effective support systems and interventions (Altun, M., et.al., 2021) Subsequently, a comprehensive discussion of these implications will be provided in the following sections, highlighting potential strategies for addressing mathematics anxiety among this specific demographic.

3.8. Comparison of Mathematics Anxiety Rating Scales: MARS vs. Diary study 1-10 scale

3.8.1. The 30-item MARS scale

Both the Mathematics Anxiety Rating Scale (MARS) and a 1-10 rating scale were used in the studies. This section compares them and explains why both were used: the reason for choosing MARS was explained in Section 2.5 and details of its use in Studies 3 and 4 are given in subsequent sections. MARS contains multiple items that assess anxiety in various scenarios, such as solving maths problems, taking tests, or participating in class discussions. This comprehensive approach enables the MARS scale to capture various anxiety triggers related to different aspects of mathematical tasks. For example, a student may feel anxious about timed tests but not about classroom participation. By addressing these specific scenarios, MARS can provide a more nuanced and detailed accurate understanding of a student’s anxiety.

3.8.2. Diary study 1-item scale

In contrast, a custom 1-10 scale used in the diary study asks the single question, such as, "On a scale from 1 to 10, how anxious are you about mathematics after playing the game today?" This type of measurement is quicker and simpler, asking students to rate their overall anxiety level. It can be completed in seconds, making it a practical tool for situations where time is limited, such as classroom settings or daily evaluations of educational interventions. The brevity of the scale allows for more frequent assessments, helping educators track changes in anxiety over time without overwhelming students with a lengthy questionnaire (Dondio et al., 2023). Immediate feedback is particularly useful for monitoring the overall impact of interventions, such as an educational game, without delving into the specifics of what may be causing anxiety. The quick turnaround in data collection can assist in making timely adjustments to teaching methods or game design to better address students' needs (Bryant, 2023).

This format aggregates all aspects of anxiety into one overall score, which can lead to a generalised response. Since it does not differentiate between specific sources of anxiety, it may overlook important details about the causes or triggers of a student's anxiety. For example, after playing a game, a student might rate their anxiety as a "6" without distinguishing whether it arises from test anxiety or general discomfort with numbers. In contrast, the MARS allows researchers to determine whether the game specifically reduced anxiety in certain situations (e.g., computation tasks or word problems).

In summary, the participant selection process was intentional and aligned with the mixed methods nature of the study. By acknowledging the diversity within the participant pool and emphasising the prominence of PhD students, we aim to illuminate the intricacies of mathematics anxiety across various academic levels. In the subsequent sections, we will delve into the specific findings and implications for each participant group, ensuring that the distinctiveness of their experiences is appropriately highlighted.

3.9. Strengths and challenges of self-reporting questionnaires as data collection tools

Self-reporting questionnaires are widely used in educational and psychological research due to their ability to capture subjective experiences efficiently and at scale. In the context of studying mathematics anxiety, these tools have proven instrumental in quantifying emotional and cognitive responses to mathematical tasks. While they offer unique advantages, such as scalability and accessibility, they are not without limitations, which need to be critically examined to ensure the validity and reliability of data.

One of the key strengths of self-report questionnaires is their efficiency. They allow researchers to gather data from large cohorts of participants quickly, making them particularly useful for studies requiring diverse sample populations. Additionally, self-report questionnaires provide direct access to participants' subjective experiences, offering insights into their personal emotions and perceptions that might not be observable through other methods. Instruments like the Mathematics Anxiety Rating Scale (Richardson & Suinn, 1972) exemplify their utility in capturing nuanced psychological phenomena.

Despite these strengths, self-reporting questionnaires are susceptible to certain challenges. Social desirability bias is a common issue, where participants may provide responses they believe are socially acceptable rather than reflecting their true feelings or experiences (Fisher, 1993). Recall bias can further compromise the accuracy of self-reported data, as participants may struggle to accurately remember past experiences or events (Loftus, 2003). Variability in interpretation is another concern, as participants may understand questionnaire items differently depending on their cultural or contextual background, leading to inconsistencies in the data. Furthermore, while self-reporting questionnaires provide valuable snapshots of participants' emotional states, they often fail to capture real-time fluctuations in dynamic phenomena like anxiety (Schwarz, 1999).

To address these limitations, this study employed several strategies to enhance data quality. First, self-reports were complemented with physiological measures, such as eye-tracking and facial emotion analysis, to validate the reported levels of mathematics anxiety. This multimethod approach ensured that the data reflected both subjective experiences and objective indicators. Second, the questionnaires underwent extensive pilot testing to refine ambiguous items and tailor them to the specific cultural and contextual characteristics of the University of Sheffield's student population. Finally, the questionnaire items were contextualized to reflect everyday mathematical scenarios, ensuring ecological validity and enhancing participants' ability to relate to the questions.

Ethical considerations played a significant role in ensuring the integrity of self-reporting data. Participants were assured of the confidentiality and anonymity of their responses, reducing the likelihood of social desirability bias. Clear information about the study's purpose was provided, fostering a sense of trust and encouraging honest participation.

4. Methods adopted for the research studies

4.1. Study 1: methodology

This exploratory study was conducted to determine the feasibility of the usability lab portion of the research. The overall process is shown below and explained in further detail in this section.

1) Recruit five students from the Information School department to participate in Study 1.
2) Students fill in the demographic questionnaire.
3) Students observed playing each game until completion.
4) Interview students about their experience playing the game and any impact on mathematics anxiety levels.
5) Transcribe, code analyse facial reactions, think aloud and gameplay data.
6) Transcribe and code and analyse interview data.
7) Select which game(s) to use for Study 3 based on the data
8) Identify attributes of a game that reduce mathematics anxiety.

There were four aims for Study 1:

- To test available equipment and data collection instruments such as the demographic questionnaires.
- To identify usability issues with the games that may make them unsuitable for further study (e.g. connection speed, compatibility with browser).
- Determine from participants which game has the most replayability and could be played over a longer period (e.g. the 30-day long Study 4 (main study)).
- Develop a list of attributes for a game that reduces mathematics anxiety that would be used when considering for other games to use for study.

Additionally, it allowed the researcher to develop skills in data collection and analysis with human participants. The study received ethics approval by the Information School (see Appendix C).

For Study 1, five students on different courses within the faculty of social science at the University of Sheffield took part, further details of the demographics can be found in the Study 1 analysis – "Demographics" section below.

Three games were identified based on their characteristics for potential usage for the Study 3 and Study 4 (Algebra Meltdown, the BBC's Giving Change Game and Ordering Fractions - the choice of games is described in detail in section 4.1). Using convenience sampling, five students within the Information School at the University of Sheffield were invited to complete a games usability study (the recommended size when conducting usability studies (Nielsen, 2000)). Convenience sampling was used as it is easier to locate participants and persuade them to take part in the study (the participants were studying in the same department as the researcher). This allowed the data collection process to take place in a shorter period of time, making more time for analysis and an earlier start for Studies 2 and 3.

4.1.1. Demographics questionnaire

Students were asked to complete a demographics questionnaire allowing the researcher to build a profile of participants and help add context to the participant's responses during the observations and interviews. Participants had no issues completing the questionnaire, aside from when asked to describe their nationality, for which one participant asked if this was the legal nationality or the one they personally identify with. The questions are nearly identical to the Study 3 demographic questionnaire, however in Study 3 the researcher included a question querying when the participant last studied a mathematics qualification, as this may also affect mathematics anxiety levels (Hodgen et al., 2014).

4.1.2. Games to potentially use for this study

Taking into account the definition for educational computer games mentioned in the literature review, the researcher could have used the same conceptual mini-games as in his Master's dissertation (Bonne, 2010), or one of the games found in the systematic literature review. Unfortunately, those games are no longer available online. However other types of educational computer games were found to be viable for use in the study that may be more effective specifically for reducing mathematics anxiety.

The games in Table 9 below were considered for use with the study. These games were shortlisted as they were not aimed at a particular age group or were designed to be suitable for 12 year olds or over, making them suitable for university level students. Most of the games are browser-based making them easier to administer than for example, console, board games or offline desktop games that require extra hardware and installation requirements to play.

An additional category was added to the table, titled “Mathematics Game or Game Involving Mathematics”. Here the researcher defines “Mathematics Games” as games where mathematics is the central purpose. For example, the aim of Algebra Meltdown (used in Study 1) is to teach algebra. This is in contrast with a “Game Involving Mathematics”, where the main purpose is to teach a varying range of subjects, or alternatively, the game could be designed primarily for entertainment purposes, but contain some segments where mathematics proves helpful for making progress in the game (such as World of Warcraft).

The list of games is not exhaustive and was found by simply searching “math games for adults” in Google and browsing around 7 pages of results. There may be more games that could be acknowledged. However, this table was put together during the Study 1 stage of the research where the main purpose was to see if the methodology is feasible, and gather participant opinion on the ideal mathematics game for future searches. As seen throughout Study 1 to Study 4, more games were found during the duration of the research.

Table 9: Games for potential use

Game	Multi-player?	Target age-group	Platform	Mathematics Subject	Timed?	Mathematics Game or Game Involving Mathematics?
Algebra Meltdown	N	12+	Online game (Browser based)	Linear Equations	Y	Mathematics Game
World of Warcraft	Y	13+	PC or MAC (online only)	Probability, Statistics	N	Game Involving Mathematics
Tug Team Fractions	Y	N/A	Online game (Browser based)	Fractions	N	Mathematics Game
Warhammer	Y	N/A	Board Game	Probability, Statistics	N	Game Involving Mathematics
BBC - Any Fractions Methods Game (Study 1)	N	N/A	Online game (Browser based)	Fractions	N	Mathematics Game
BBC – Giving Change Game (Study 1)	N	N/A	Online game (Browser based)	Addition/Subtraction	N	Mathematics Game
Star Dash Studios (Study 3)	N	N/A	Mobile game	Addition/Subtraction, Fractions	Y	Mathematics Game
Bubble Function (Study 4)	N	N/A	Mobile game	All mathematical operations	N	Mathematics Game
BBC – Ordering Fractions Game	N	N/A	Online game (Browser based)	Fractions	N	Mathematics Game

Three games from the list above were considered suitable for Study 1. The first one was an online browser-based game called Algebra Meltdown from Manga High Games (now unavailable due to being replaced by more popular games). In particular, the game focuses on linear equations, a topic students of all backgrounds find somewhat difficult (Hartmann & Sprenger, 2010).

Additionally, it is a browser-based game meaning it can be accessed via a range of desktop and mobile devices. In this game, players are recruited by a nuclear engineering company and placed in charge of a nuclear generator, passing atoms to scientists so they can keep the generator working. The user is given linear equations to solve and have to answer them by selecting the atom containing the correct answer from a tube and passing it down a long pipe to the correct scientist. The equations can be easy or difficult depending on the user's preferences. If the game becomes too hard, users can press the coffee break button, which temporarily pauses the game, giving users more time to think about the question. Users also have a general pause button that halts the game for however long they want. The end goal is the development of "The Device". Users are not told what the device is until the game is complete. Additionally, user feedback on answers is immediate, meaning users could potentially experience success as regularly as possible, a factor already proven to reduce mathematics anxiety (Bakker, van den Heuvel-Panhuizen, & Robitzsch, 2015). The game also provides tutorials introducing equations as well as adding and subtracting negative numbers to help users who may be unfamiliar with the concepts.

A limitation with this game is that it is timed, requiring quick responses to questions. This is a feature of mathematics learning that has been shown to increase mathematics anxiety and sometimes reduce test performance due to being forced to rush answers under pressure (Boaler, 2014; Tsui & Mazzocco, 2006). However, it was anticipated that participants with low test anxiety might experience less mathematics anxiety with the game due to being able to handle timed tests (Qashoa, 2012).

For comparison of preferences between timed and untimed games, another game was found that could be used for the study, which was aimed at adults, but was untimed. The "Ordering Fractions Game" from BBC Skillwise gets players to put a set of fractions in order. There are three different difficult levels users can choose from. Participants have five "lives", meaning when they get 5 questions wrong, the game is over. The game comes with its own set of instructions, and also a link to factsheets that explain the concept of fractions using videos and worksheets. This game has its own limitations, in that there is no story or real-world application to the questions. Instead, users simply drag and drop fractions into appropriate slots then restart the game.

An additional game was found to address the issue of real-world application and timed questions. The “Giving Change Game” also by BBC Skillswise gets users to calculate change from a £5, £10 or £20 note provided by a customer. Players drag and drop coins and notes from a till into the customer’s hands. When the player has finished counting change, pressing enter gives them feedback on their answer. There are three difficult levels users can choose from, each with just five questions to answer, meaning the game can be completed relatively quickly depending on the user’s speed. The progressive difficulty makes it easier to allow users to get used to the game’s functions and build confidence, and secondly fluctuations in difficulty levels will stop participants becoming bored (Chanel, Rebetez, Bétrancourt, & Pun, 2011). Additionally, the game is untimed so users can arrive at their answers at their own pace, so performance is less likely to be hindered by anxiety.

It was decided to test all three games in Study 1, to see whether they directly affected mathematics anxiety in some way, as well as to see which game participants preferred from a usability standpoint.

Board games/table-top games were also considered as an approach for gaming, with the possibility of the study expanding beyond computer games. They do have the advantage of encouraging social interaction with face-to-face communication, which has potential to reduce mathematics anxiety due to players being able to share tips amongst themselves (Kindermann & Skinner, 2009; Mandryk & Maranan, 2002). However, online games, despite there being less interaction between users in game (e.g. no face to face), have the advantage of being played by anybody, anywhere at the same time with an internet connection and therefore are easier to administer for the study.

4.1.3. Gameplay observation

The questionnaire was followed by an observational study of the participant playing each game. Participants started with Algebra Meltdown, then played the Giving Change game, followed by the Ordering Fractions game. While there was no reason for playing the games in this order, all participants followed the same procedure for consistency purposes. Gameplay time was limited to 10 minutes, as the entirety of the game’s functionality can be experienced within this time frame, after this, the game's content is repeated but at higher difficulty levels (e.g. more difficult mathematics questions). The participant's facial expressions and gameplay were video recorded. Participants were also encouraged to think-aloud as they are playing to express any positive, negative feedback, how anxious they were feeling or general observation about their experience with the game. Mouse movement was also recorded to identify areas of the game participants struggled or felt most confident with from a usability standpoint.

The iLab set up had a PC that the participant used for the game. Morae Recorder software was installed for recording on screen gameplay. This room was set up to record audio and video, featuring a Microsoft webcam attached to the top of the monitor. The control room next door was also used, featuring a 2-way mirror allowing the researcher to observe the participant as well as video record their behaviour.

Observation data was analysed using video analysis software Morae Manager available from the control room. Videos contained the participant's gameplay with a Picture in Picture (PIP) video of the participants face (see Fig 4), allowing the researcher to triangulate facial reactions and think aloud data with the participant's gameplay more easily.

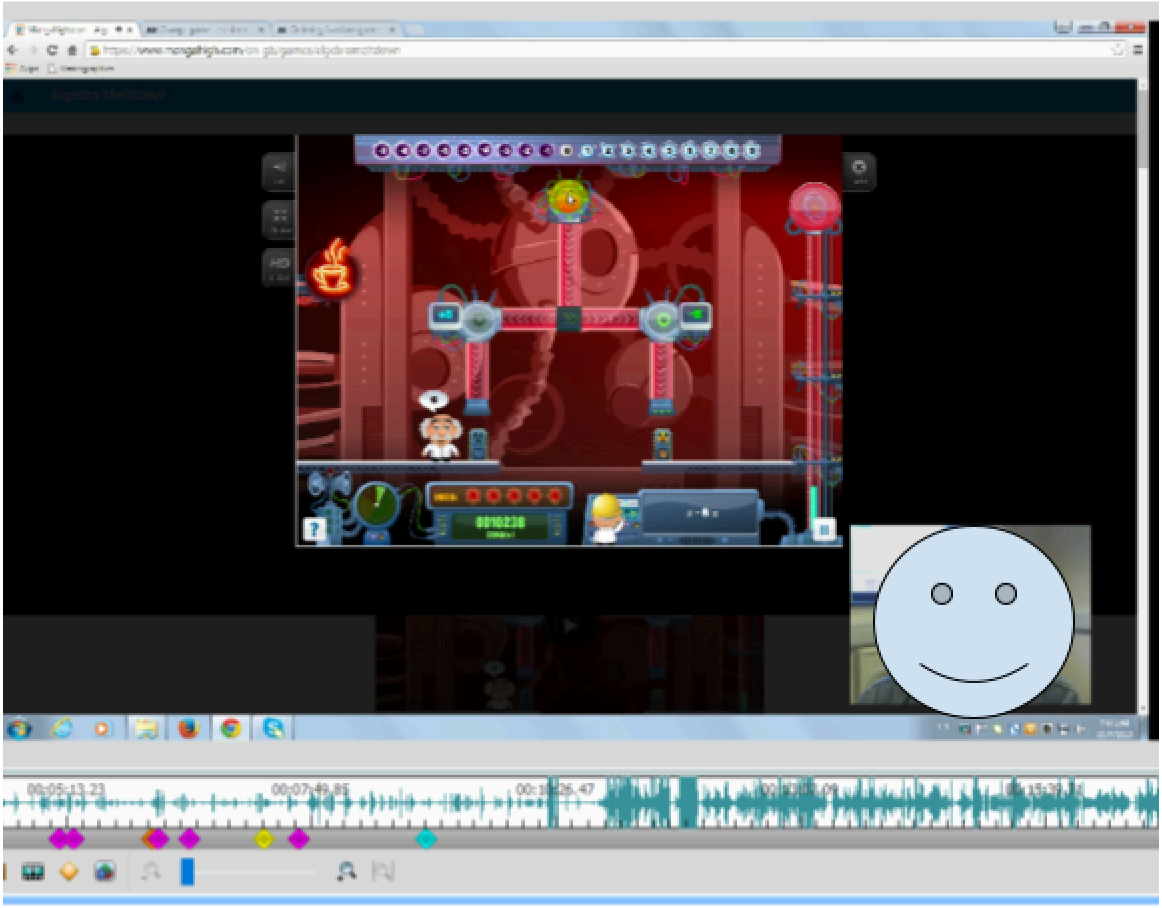

Figure 4: Algebra Meltdown Morae Manager analysis
(participants face hidden to protect anonymity)

Videos were coded using Morae Manager's marker system. A more deductive approach to coding, this comprises five different markers, "Click link", "User needs help", "Navigation", "Observation", "Search", "Video", "Error". These colour coded markers refer to important events and think aloud activity occurring while interacting with the game. After adding these markers to a particular event in the timeline the researcher can add a description of an event. Morae Manager also allows the researcher to select a score when a marker is added indicating the severity score of an event (Severe – 0, Medium - 1, Minor - 2).

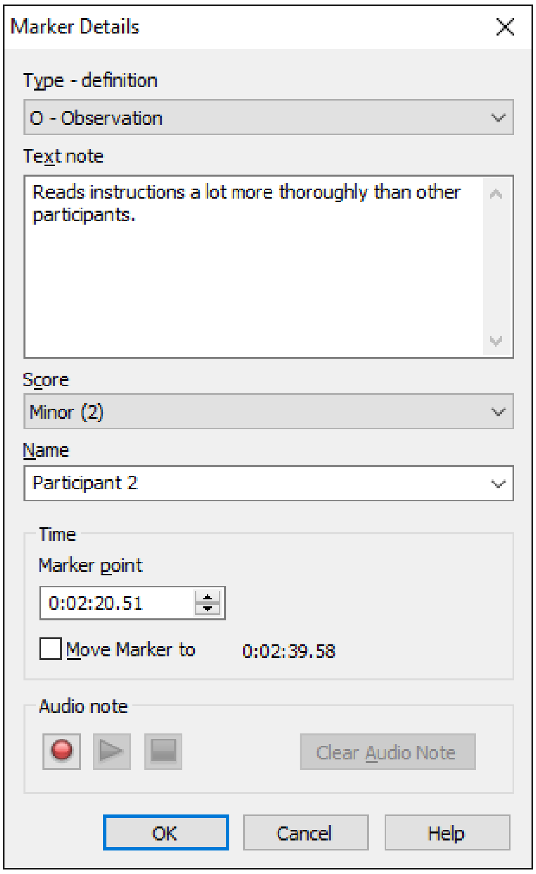

Figure 5: Example of usability markers in Morae

All events are mentioned in the analysis. The raw descriptions could have been coded and categorised to form a middle level of codes, however there was a shortage of time, and the narrow range of significant events occurring meant analysis was manageable based on the small amount of raw descriptions and marker types alone. Analysis was carried out straight after each session while events were still fresh in the researcher's mind. The markers were revisited a few months later, identifying some events that were not added in the correct place on the timeline, and were adjusted accordingly.

4.1.4. Interviews

After each game, participants were interviewed to determine what areas of the game affected their mathematics anxiety levels, and what they liked or disliked about the game from a usability perspective. The usability questions were based on the (Procci, Chao, Bohnsack, Olsen, & Bowers, 2012) educational games usability study. This helped determine any usability advantages/issues with the games, as well as start the development of a usability criteria for a game that reduces mathematics anxiety. Once all three games had been covered in the interview, the participant was finally asked which game they preferred overall.

Due to the terminology used in the usability-based questions, there were issues getting participants to understand what was being asked, and the researcher had to clarify vocally what the questions meant. Subsequently, the questions were presented to the (now defunct) Postgraduate Research writing group at the University of Sheffield's iSchool, whose members had little to no knowledge of educational computer games and felt the terminology used in the questions were too technical. It was suggested that the interview questions be revised if conducting a future usability study on games to ensure they could be more easily understood by a wider audience. The questions were revised to form the final version of the usability interview questions (see Appendix D).

Interview analysis used a more thematic analysis approach, as the participant's responses to the semi-structured interview provided a vast and in depth amount of data to analyse. Interview data was audio recorded and handwritten notes were taken. When all interviews were completed for a participant, the recordings were immediately transcribed in MS Word, adding any handwritten notes where audio may have been inaudible or where the researcher had observed an event that the audio interview did not capture. The interview transcripts were then imported into NVivo for coding.

Open coding was used to help identify any new concepts (e.g. user experience, anxiety related) that may occur in the participant's responses to the questions (Burnard, 1991). Analysis began by going the general to specific, the most obvious categories were identified first e.g. Instructions, Structure, Game progression. These were categories based on key terms from the (Procci et al., 2012) game-usability interview questions and inevitably appeared in the participants' responses due to the terms appearing in the interview questions. Furthermore, the participant sometimes touched on a subject that was not a key term in the interview questions, such as "Real world application" but did not go into any detail. These were also included as general categories. The researcher then read through the data transcripts again identifying codes to add the categories. For example, the category "Learning" consists of the codes "Did not learning anything" and "Makes use of existing skills", "Not much to learn", and "Skill improvement". Some codes were expanded into lower level codes, for example "Skill improvement" was expanded into "Faster thinking" and "Good for mental mathematics".

Conversely, going from specific to general meant specific codes were discovered and grouped together to form new categories. For example, “Reward systems is clear” and “Confusing reward system” were grouped to form a “Reward” category.

In terms of identifying the attributes of a game that affect mathematics anxiety, this was done by identifying from questions about anxiety while playing the game. In this case, the codes identified were as follows (see Appendix E for the full list of codes and categories and sub-categories).

- Anxiety caused by feedback
- Anxiety caused by getting wrong answers
- Anxiety caused by harder difficulty
- Anxiety caused by interface
- Anxiety caused by problem solving
- Anxiety caused by real world application
- Anxiety caused by reward system
- Anxiety caused by structure

From the list of codes and lower level codes a theme or a number of themes were created.

Both the observation and interview data is discussed in the findings (see section 4.2). To help with triangulation, findings from the observation were checked against findings in the interviews to not only help validate discoveries, but also identify why certain events occurred in the observations. Additionally, it was possible to observe participant claims of events occurring during the interviews and verify their accuracy using the observation data.

There were several limitations to this analytical approach. The first being that it is carried out from the single perspective of the researcher, and the transcripts may be interpreted differently by another researcher. Furthermore, the codes were never checked with the participants themselves, which may have been helpful in spotting potential misunderstandings of the participant’s responses. In terms of processes, the coding of interview and observation data could have been better integrated by importing all videos into NVivo and coding both interview and observation datasets simultaneously, potentially making it easier to triangulate the data.

4.1.5. Data collection overview

Table 6: Study 1 - Data recording times and file sizes

Type of Footage	Time per Participant (min)	Total Time for 5 Participants (min)	File Size (MB)	Total Data Size for 5 Participants (MB)
Audio interviews	9.8	49	13	65
Gameplay observations (Game 1)	9.6	48	137	685
Gameplay observations (Game 2)	10.2	51	137	685
Gameplay observations (Game 3)	10.5	52.5	137	685
Total		200.5		2,120

The Study 1 data with 5 participants and 3 games tested was important for planning Study 4 that involved 17 participants and 1 game being tested. This for the following reasons:

Usability assessment

Study 1 aimed to determine which of the 3 games was most usable for Study 4. By evaluating the average time spent by participants on gameplay observations for each game, Study 1 provides insights into the feasibility and engagement levels of the games. This information helps in selecting the most suitable game for the Study 4, ensuring that the chosen game maximizes participant engagement and provides accurate data on its impact on mathematics anxiety.

Time estimation

The total time for gameplay observations in Study 1 (200.5 minutes) provides an estimate of the time commitment required from participants in the Study 4. Scaling up this time estimate to accommodate 17 participants and considering the potential variations in gameplay observation times helped in planning the Study 4's duration. It ensured that the study was designed with a realistic timeline that participants could comfortably adhere to, and allowed the researcher to allocate sufficient resources for data collection.

File size and data management

Understanding the typical file size and total data size for different types of footage (audio interviews and gameplay observations) is crucial for data storage and management during Study 4. Study 1 provided an idea of the expected file sizes and total data size, enabling the researcher to anticipate storage requirements and plan accordingly. This ensured that appropriate infrastructure and resources were available to handle the data generated during Study 4.

Participant selection and recruitment

The Study 1 data with 5 participants helped to inform the recruitment process for Study 4 involving 17 participants in identifying practical strategies for recruitment.

By considering these factors, the Study 1 data aided in the planning and design of Study 4 on educational computer games' impact on mathematics anxiety in university students. It facilitated informed decision-making regarding game selection, time estimation, data management, and participant recruitment, ultimately contributing to the success and validity of Study 4.

4.2. Study 2: Everyday mathematics study methodology

Study 2 explored how university students use mathematics in everyday life. The goal was to gather data on students' day-to-day mathematical activities and skills to inform the fishbone model of factors influencing mathematics anxiety and to guide realistic game scenario design. An exploratory, mixed-methods survey was employed. The study was approved by the Information School ethics committee (GDPR-compliant) and used an online questionnaire distributed in January 2017 via the University of Sheffield's student volunteer mailing list. This approach invited students from all faculties and study levels (undergraduate, postgraduate, etc.) to participate, ensuring broad representation. The data collected from this study provide foundational insights into students' mathematical engagement outside the classroom, which can be used to design educational games with relatable everyday contexts.

4.2.1. Study design and methodology

The study followed an exploratory survey design, combining quantitative summary and qualitative thematic analysis. The design of this study was informed by prior research suggesting that embedding mathematics in everyday contexts enhances engagement and reduces anxiety (see Section 2.6). The key steps in Study 2 included:

- **Recruitment:** Students were recruited via the university's volunteer mailing list (January 2017), open to all disciplines and levels.
- **Questionnaire distribution:** A Google Form questionnaire was created and emailed to the volunteer list, collecting data in a short time span consistent with the study's exploratory nature.
- **Demographics and activities:** The survey asked participants to provide demographic information (age range, gender, degree level, and discipline) and to list everyday activities involving mathematics (e.g. budgeting, cooking, gaming), describing the math skills used in each.
- **Self-assessment:** Additional items asked students to rate their competence and confidence in performing the listed activities.
- **Data summarisation:** Quantitative responses (e.g. frequencies of activities and demographic distributions) were summarized using counts and percentages, to reveal patterns of engagement.
- **Qualitative coding:** All valid survey responses (125 participants) were imported into NVivo. Responses to open-ended questions ("Where were you? What were you doing? What math was involved?") were coded using Braun and Clarke's (2006) six-phase thematic analysis. Two researchers coded a subset of responses independently to ensure reliability.

- **Ethics:** Anonymity was maintained (names and emails were not collected), participants could skip any questions, and all procedures were approved by the ethics committee and fully GDPR-compliant.

This mixed-methods approach ensured both breadth (counts of activities) and depth (themes of math usage) in understanding students' everyday mathematics.

4.2.2. Aims and methods

The data derived from the study on everyday mathematics conducted with university students can furnish valuable insights for formulating a fishbone model to investigate the impact of educational computer games on mathematics anxiety among university students. The purpose of this segment of the research was to delve into how students integrate mathematics into their day-to-day lives. The resulting findings could then be integrated into the framework of a narrative for a game centred around real-life mathematical activities that participants can personally connect with.

Initially, the plan was to devise a game based on the usability preferences unearthed in Study 1. This game would subsequently be employed in a pilot study (Study 3) and later in Study 4. These follow-up studies aimed to uncover additional usability preferences and game features that influence mathematics anxiety.

However, as the research progressed, it became evident that the task of game design lay beyond the scope of Study 4. Consequently, the objective to create a game was abandoned. Nevertheless, the primary objective of investigating everyday mathematics was retained, as it contributes to a better understanding of students' interaction with mathematics. The outcomes of this research are still valuable to game designers. These findings, when combined with the model of factors influencing anxiety as presented in Chapter 6, can aid in the development of effective educational games. These games can be designed to incorporate scenarios that resonate with the players, thereby enhancing their engagement and potentially alleviating mathematics anxiety.

In summary, the data collected from the study of everyday mathematics among university students could serve as a foundational element in constructing a fishbone model that examines the influence of educational computer games on mathematics anxiety. While the original plan to design a game was altered, the insights gained from studying students' mathematical engagement remain applicable to inform the creation of educational games that are more relatable and effective in addressing anxiety-related concerns.

This study had three main aims:

1. To discover what everyday activities students perceive as involving mathematics.

    1.1 **Identification of relevant contexts:** Understanding the contexts in which students encounter mathematics daily helps to pinpoint specific scenarios that may trigger or alleviate anxiety. This information can be categorised under the "environment" branch of the Fishbone model.

    1.2 **Designing realistic game scenarios:** Insights into everyday mathematical activities can guide the development of game scenarios that are relatable and relevant, enhancing student engagement and reducing anxiety through familiarity.

    1.3 **Personal relevance:** By connecting educational game content to everyday experiences, the games can become more meaningful and less intimidating, thus potentially reducing anxiety.

2. Discover what mathematical concepts students recognize in their everyday lives.

    2.1 **Conceptual mapping**: Identifying the mathematical concepts that students encounter daily allows for a mapping of these concepts onto the Fishbone model under the "content" or "subject matter" branch. This helps in understanding which concepts are more anxiety-inducing and why.

    2.2 **Tailored content**: Games can be designed to address specific mathematical concepts that students find challenging or anxiety-inducing in their daily lives, providing targeted practice and reinforcement.

    2.3 **Cognitive familiarity**: Recognising familiar concepts within games can help reduce cognitive load and anxiety, making it easier for students to engage with the educational content.

3. Compare identified mathematics activity amongst students with Bishop's (1998) typology of everyday mathematics.

    3.1 **Categorisation and benchmarking**: By comparing students' mathematical activities with Bishop's typology, the study provides a structured framework for categorising these activities. This structured approach can be directly applied to the Fishbone model to systematically analyse the sources of mathematics anxiety.

3.2 **Identifying gaps and overlaps**: This comparison helps to identify gaps in the current educational approaches and potential overlaps where educational games can be most effective. These insights can be used to refine the "methods" and "strategies" branches of the Fishbone model.

3.3 **Theoretical validation**: Aligning real-world findings with established typologies like Bishop's provides theoretical validation for the factors identified in the Fishbone model, ensuring that the model is grounded in both empirical data and academic theory.

4.2.3. Participants and sampling strategy

Similar to Study 4, the analysis of the everyday mathematics data in Study 2 encompassed a mixed methods approach combining inductive and deductive coding. The literature recommends this approach to thematic analysis for studies involving the "everyday" due to the subjective meaning of experience that could leave participants projecting various interpretations of what constitutes mathematics (De Lange, 2003; Edwards et al., 2011; Schutz, 1967).

Participants were university students who responded to the survey. In total, 126 students submitted the questionnaire; after removing one incomplete record, 125 valid responses were analysed. Recruitment was open to the entire student body via the volunteer mailing list, and students from all faculties and course levels were invited. The final sample was primarily composed of psychology undergraduates from a single institution. Although this limited the generalisability to other disciplines, the sample's demographic profile (gender and age distribution) reflected that of typical UK psychology cohorts. Recruitment via a volunteer list meant the sample was self-selected; however, this process still produced a reasonable mix of students with varying levels of mathematics confidence. While the sample is not fully representative of the entire university population, it was considered adequate for the exploratory aims of the study.

4.2.4. Data collection

Data were collected via an online survey. A Google Form questionnaire was used (created with ethics approval) and distributed in January 2017 through the University of Sheffield's student volunteer mailing list. This electronic questionnaire included: demographic items, prompts to list everyday activities involving mathematics and the math skills used in each, and questions about self-rated competence and confidence in those activities. For example:

- **Demographics:** Participants reported their age range, gender, degree level, and study discipline.
- **Everyday activities:** Students listed activities they perform that involve mathematics (e.g. budgeting for shopping, cooking measurements, gaming) and described the types of math involved in each activity.
- **Self-assessment:** The survey asked how competent and confident participants felt about those activities.

The survey yielded 126 responses, of which 125 were complete and valid for analysis. This approach allowed collection of quantitative data (frequencies of activities and demographics) alongside qualitative descriptions of students' experiences.

Throughout the process, NVivo was used to facilitate coding and analysis of qualitative data. To ensure reliability, an intercoder check was conducted: a second researcher independently coded a subset (33.6%) of the responses. This check yielded a high percentage agreement and Cohen's kappa around 0.8, indicating that the coding was consistent. The analysis centered on identifying the most common everyday tasks and associated mathematics, which could then inform game scenario design.

Although the sample size provided sufficient data for analysis, it was not fully representative of the wider university population. Participants were primarily psychology undergraduates from a single institution, which will limit the generalisability of the findings to other academic disciplines or universities. However, the demographic balance of gender and age reflected that of typical UK psychology cohorts (Universities UK, 2021). Recruitment through the university volunteer list means participants were self-selected, however, this ensured a reasonable mix of students with varying levels of mathematics confidence. Therefore, while caution should be exercised when generalising these results, the sample was suitable for the exploratory aims of the study.

4.2.5. Study 2 - ethical implications

Ethical procedures were followed throughout Study 2. The study received prior approval from the University of Sheffield's ethics committee. Participation was voluntary and based on informed consent. The consent form clearly explained any potential risks (for example, that questions might prompt discussion of sensitive activities such as gambling) and participants' rights. All data were collected anonymously: personal identifiers (names, emails) were not collected, ensuring confidentiality. Participants were informed they could skip any question they preferred not to answer and could withdraw from the study at any time without penalty. No deception was used at any stage. The combination of ethical review, anonymity safeguards, and clear withdrawal procedures ensured that participants' rights and well-being were protected throughout the study.

4.2.6. Study 2 analysis summary

To analyse the data, the UOR (2001) approach to survey analysis was adapted for the researchers study. The first stage was describing the population, identifying any potential trends in responses amongst the demographics of participants and attempting to explain how this may affect the Study 2 results as a whole.

Secondly, responses on everyday mathematics experiences were initially scanned through, coded and themes developed. The intention was to develop themes representing overall tasks carried out and the mathematics involved. The most common themes could be used as scenarios for a game that students find relatable.

4.2.7. Analysis

126 students responded to the survey in total; however, one record was later omitted, due to the entry being indecipherable. 125 records from the spreadsheet were imported into NViVo, where each record was coded and themed. NVivo was used as it is quicker to code and theme results than other tools and offers more qualitative focused analytics tools than other software. Basic demographic analysis was carried out including percentages for age groups, gender, study level, attendance types, student accommodation, activity involvement, and pressure to do mathematics quickly during the activity.

NVivo also has the functionality for finding trends between particular activities, locations and mathematics skills undertaken with the demographics of participants. As the main purpose of the everyday mathematics anxiety questionnaire was to identify activities and the mathematics involved, the analysis centred on these specific results.

Several initial categories were formed to help structure the codes based on three open questions from the questionnaire; "Where were you?", "What were you doing" and "What kind of mathematics was involved?". These were coded as "Location", "Activity" and "Mathematics" respectively. "Location" referring to where the participant was at the time of the activity, "Activity" referring to the event that took place that required the participant's use of mathematics, and lastly "Mathematics", referring to the type of mathematics involved in the activity.

4.2.8. Rationale for analysis of everyday mathematics data

The everyday mathematics survey data were analysed using counts and percentages to provide a clear and accessible summary of how university students engage with mathematics in their daily lives. This approach aligns with the exploratory nature of the survey, which aimed to identify patterns and trends rather than test specific hypotheses or establish statistical significance.

Using counts and percentages allowed for a straightforward presentation of the data, highlighting the frequency of engagement in different mathematical activities, such as budgeting, shopping, or planning. This method was particularly effective for categorical data, such as demographic variables and types of mathematical tasks, as it provided an intuitive way to compare responses across groups.

The decision to focus on counts and percentages was also influenced by the variability in response rates across survey questions. Some participants skipped certain questions or provided incomplete responses, limiting the applicability of more advanced statistical analyses. By focusing on counts and percentages, the analysis ensured that all valid responses were included, providing an accurate representation of the data.

Furthermore, the use of counts and percentages allowed for meaningful comparisons between subgroups, such as gender, field of study, or level of mathematics qualification, without the need for complex statistical tests. This was particularly useful for identifying broad trends and areas of interest that could inform future research or interventions.

4.2.9. Intercoder reliability

To check for objectivity and validity in the findings, an intercoder reliability test was conducted using a PhD student from an alternative field of study to carry out the coding. The student was presented with the existing codes and the everyday mathematics questionnaire data in NVivo and asked to drag and drop questionnaire responses into existing codes, or if the student felt some responses did not fit the current codebook, create their own codes.

Coding was carried out without interference from the researcher. Out of the 125 questionnaire responses from the original data set, a sample of 42 responses were coded for reliability testing or 33.6% of the sample size. While this is above the 10% recommendation for intercoder sample sizes by Allen (2017), the author recommends at least 50 units of data coded where possible, therefore the percentage agreement may not be as representative as necessary. The average percentage agreement across all coded responses amounted to 99.78%, indicating a high level of agreement. However, to account for the possibility of either coders making random guesses and reaching agreement by chance, a Cohen's kappa value was calculated. The average Kappa value across the sample came to 0.73, indicating "moderate" agreement and between 35 – 63% of the data being reliable (McHugh, 2012). The reason for the Kappa value may have been variation in the approach to coding. Whereas the 1st coder coded specific words in a response, the 2nd coder coded entire paragraphs. This could perhaps have been alleviated by the researcher by providing an indication of density of content to code.

A second intercoder reliability test was conducted on the adapted model of everyday mathematics. The second coder was the same PhD student as before. The student was provided with a copy of the adapted model, as well as definitions of each theme and examples of the mathematics involved for each theme. They were asked to use NVivo to link questionnaire responses on mathematics activity with the seven themes in the model, referring to the definitions and mathematics examples where needed. The student could create new themes to further adapt the existing model. Due to time constraints, precisely 50 units of data in the dataset were coded. No new themes were identified. The average percentage agreement amounted to 96.1% indicating a high level of agreement. The kappa value came to 0.86, indicating strong agreement (McHugh, 2012). This shows that the data collected is both meaningful, and can be applied to the new can be applied to the adapted everyday mathematics model.

One weakness in the process however, is that only one coder was used to test for reliability, and this was the same student as before who was familiar with the dataset already. Both the percentage agreement and kappa value may have been lower had more or different students been used to carry out the coding.

4.3. Study 3 methodology

Study 3 has two aims:

1) To evaluate the feasibility and functional suitability of the mobile game for implementation in Study 4.

2) To assess the clarity, comprehensibility, and overall usability of the MARS questionnaire to ensure its appropriateness for participants in Study 4.

The stages are as follows:

- Invite 5 students from social science modules (featuring mathematics) to complete MARS questionnaire.
- Students fill in a demographic questionnaire.
- Participants complete pre-game MARS questionnaire.
- Observe gameplay (Stardash studios), record clicks, and observe think aloud as participants play the game.
- Interview all participants about their experience playing the game and any impact on anxiety levels while playing.
- All participants complete the post-game MARS questionnaire to reassess mathematics anxiety levels.
- Interview participants for their feedback on the usability of the MARS questionnaire.
- Use the gathered data to adjust the methodology for Study 4 (if necessary).

4.3.1. Study 3 process

Given the informative, in-depth data acquired from Study 1, in terms of collecting data, Study 3 followed the same methodology as Study 1. Therefore those steps in the process will not be described again in this section.

However in terms of data collection the following amount of data was collected

Table 7: Study 3 - Data recording times and file sizes

Type of footage	Time per participant (min)	Total time for 5 participants (min)	M file size (MB)	Total data size for 5 participants
Audio interviews	9.8	49	13	65
Gameplay observations (Game 1)	9.6	48	137	685
Gameplay observations (Game 2)	10.2	51	137	685
Gameplay observations (Game 3)	10.5	52.5	137	685
Total	-	200.5	-	1,430

From the Study 1 data analysis, it appeared two of the three games selected as treatments (Algebra Meltdown and Giving Change) would be suitable for use with Study 4. This created an opportunity to compare mathematics anxiety levels for students playing a game using everyday scenarios (giving change in a shop) to a game with more specialist activity in Algebra Meltdown (stopping a nuclear reactor from exploding). 3 out of 5 participants stated that they preferred Algebra Meltdown overall while the remainder of the participants felt the Giving Change game was most usable. While setting up Study 3 a maths game aimed at teens and adults, Star Dash Studios, was discovered that had more in-depth gameplay and graphical features. Given the increasing popularity of mobile amongst students (de Los Santos et al.), it became necessary to test this game as a potential treatment for mathematics anxiety.

4.3.1.1. Star Dash Studios

A smartphone game by independent education charity National Numeracy was later identified as having potential to use in the study. Star Dash Studios is aimed at 16-25 year olds (the most prominent age group amongst University students is 20 or under (HESA, 2016)). The game takes place on a virtual film set, with the user playing the role of a runner carrying out various tasks on a to-do list involving mathematics. Study 3 enabled the opportunity to test mobile games as a potential treatment for mathematics anxiety. Players complete a range of mental arithmetic tasks, but done through the real world tasks such as hair dressing, transporting luggage, rather than written sums.

4.3.1.2. Participants

For participant recruitment, students from Biomedical Science were invited to take part in the study. A senior lecturer from this department was interested in investigating why students in this department seem to struggle with mathematics or avoid mathematics heavy courses altogether, and seemed the most keen for the biomedical science cohort to take part in the study. Perhaps due to lack of interest in the topic, or lack of interest in the topic only 2 students from this department took part in the study. 3 other participants were recruited from the University of Sheffield to augment the sample. As this was a Study 3, the students' course of study was not judged as critically relevant, as this part of the study was more about testing the playability of the games.

4.3.2. Use of MARS for study 3

For Study 3, a 30-item Mathematics Anxiety Rating Scale (MARS) was employed to evaluate the extent of mathematics anxiety experienced by university students when interacting with a mobile educational game. The MARS was also employed to test the scales's feasibility for use in study 4. The MARS played a pivotal role in gauging and quantifying the participants' levels of anxiety related to mathematics, offering valuable insights into the influence of the mobile game on their emotional state.

The Mathematics Anxiety Rating Scale is a commonly used instrument in research to gauge the degree of anxiety individuals feel when confronted with mathematical concepts and tasks. Typically, it consists of a series of statements or questions that participants respond to by indicating their level of agreement or disagreement with each item. In Study 3, the MARS featured 30 such items, encompassing a range of aspects associated with mathematics anxiety.

When the MARS was initially introduced in Study 3, it was administered as a pre-game questionnaire to the participating students. This timing was critical as it served to establish a baseline measurement of mathematics anxiety before the participants engaged with the mobile game. By gathering this initial data, researchers were able to evaluate the participants' baseline level of mathematics anxiety and subsequently compare it to their anxiety levels after interacting with the educational mobile game.It was administered again post-game, so that mathematics anxiety levels could be compared.

Here are key points to consider regarding the use of the Mathematics Anxiety Rating Scale (MARS) in Study 3:

Baseline assessment

The administration of the MARS before gameplay allowed researchers to create a clear starting point for each participant's mathematics anxiety. This baseline measurement acted as a reference for assessing any alterations or shifts in anxiety levels resulting from the mobile game experience.

Quantitative measurement

The scale's 30 items encompassed a broad spectrum of scenarios and situations associated with mathematics. Participants' pre- and post-game responses were scored, offering a quantitative measure of mathematics anxiety that could be statistically analysed.

4.4. Study 4 - methodology

Figure 5 outlines the research design for Study 4's methodology. At this stage the choice which game to use for the study had been narrowed down to Manga High's Bubble Function game.

The objectives of Study 4 were as follows:

1. To investigate the impact of an educational computer game (Bubble Function) on participants' mathematics anxiety.
2. To identify the game attributes that influence mathematics anxiety.
3. To develop a fishbone (cause-and-effect) model explaining the factors that contribute to fluctuations in mathematics anxiety during gameplay.

Further details of the full methodology and choice of game are explained following the diagram.

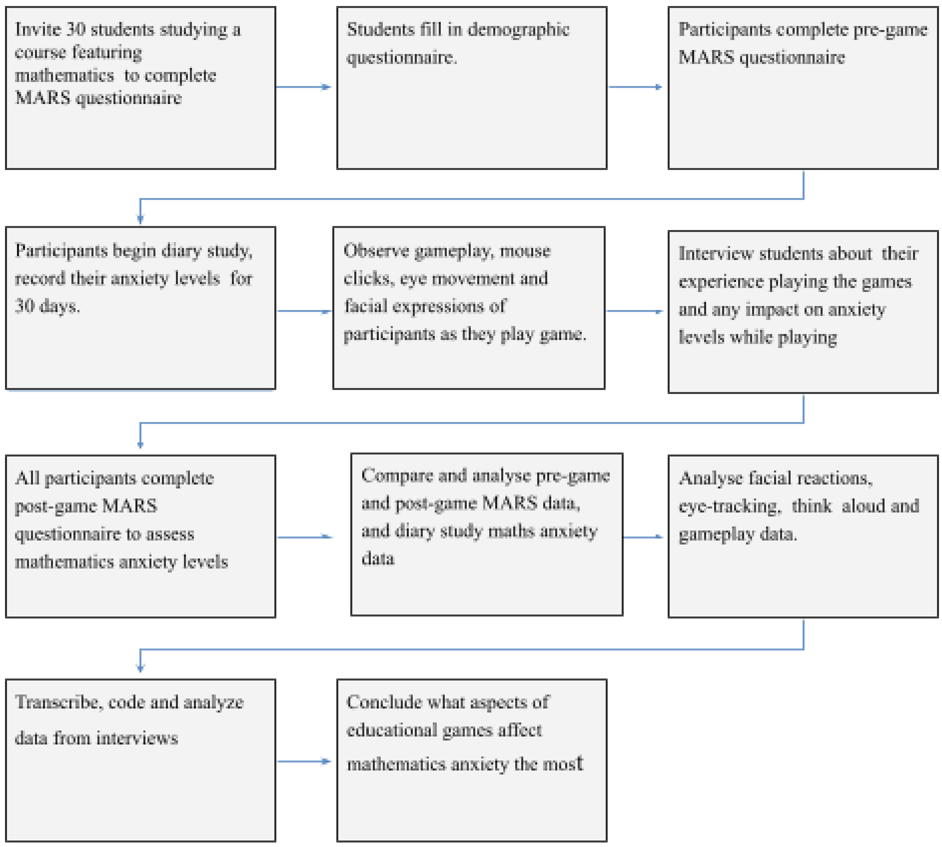

Figure 6: Study 4 research design

The methodology for Study 4 consists of three parts. In line with the objectives of the study, a pretest MARS questionnaire was used to investigate the extent to which mathematics anxiety was an issue amongst the participants. Participants were given the Manga Highs Bubble Function game to play alongside a diary study so they could document their mathematics anxiety levels on a daily basis and their player experience. Participants were then invited to take part in interviews and observations akin to the Study 1 and 3 but this time including an eye tracking study. Eye-tracking hardware was introduced to the university's usability lab in the autumn of 2019, presenting an opportunity to integrate this feature into the data collection process and identify trends between mathematics anxiety and eye movement which few to no studies have explored. A post-test MARS questionnaire was provided to all participants allowing the researcher to identify any differences in mathematics anxiety levels after playing the game.

4.4.1. Transition back to desktop games from mobile games

The rationale for Study 3 emphasised the increasing popularity of mobile devices among students as a key factor for selecting games to test for reducing mathematics anxiety.

However, the games ultimately used in the Study 4 were desktop-based. This shift reflects deliberate decisions based on findings from Study 3, practical considerations, and the compatibility of the university's resources.

While mobile platforms are widely accessible and increasingly used by students, Study 3 revealed several limitations in their application for this research. Many mobile educational games lack the complexity and depth needed to address university-level mathematics anxiety effectively (Papadakis & Kalogiannakis, 2017). Additionally, technical constraints such as screen size and limited customisation options posed challenges for creating immersive and adaptable learning environments.

The decision to use desktop games for the Study 4 was further influenced by the compatibility of tools available in the university's iLab. The eye-tracking equipment, which was integral to capturing participants' physiological responses to anxiety, was designed exclusively for desktop PCs. Mobile games were incompatible with this setup, making it challenging to obtain detailed behavioural data. Similarly, tools such as Morae Recorder and Morae Observer, which were used to record and annotate usability issues in real time, were unavailable for mobile platforms. These limitations in data collection infrastructure necessitated the transition to desktop games.

Another consideration was the potential for distractions inherent to mobile devices. Incoming calls, notifications, and the presence of other applications could interfere with gameplay and affect the user experience, introducing confounding variables that would be difficult to control in a research setting. By contrast, desktop PCs offered a controlled environment that minimised external distractions, ensuring consistency across participants.

Desktop games also provided richer gameplay mechanics, more robust user interfaces, and the ability to integrate adaptive difficulty levels, features critical for addressing anxiety and enhancing engagement. The standardised hardware in the iLab further ensured consistency in gameplay experience, eliminating variability caused by differences in device specifications.

While the rationale for Study 3 reflected an initial exploration of mobile games, the transition to desktop games in the Study 4 reflects a considered and evidence-based adjustment. This approach ensured that the study leveraged the full capabilities of the university's resources while addressing practical limitations of mobile platforms.

4.4.2. Bubble Function

Study 1 and 3 was used to assess which games would be suitable for Study 4, with Algebra Meltdown, Giving Change determined as the most engaging amongst participants. However, Algebra Meltdown was pulled from Manga High's servers in 2019 due to a lack of users playing the game on their platform. Additionally, Giving Change was pulled from the BBC's Skillswise website, and replaced with a game aimed at KS1 (Key Stage 1 students (5 - 7-year olds). In an attempt to find a replacement, the researcher contacted Manga High to ask for the most appropriate replacement for Algebra Meltdown that could be used for Study 4, this was due to Manga High having a much bigger collection of games aimed at all ages than the BBC. Manga High recommended the game Bubble Function, due to the wider assortment of maths problems available and familiarity with popular entertainment games such as Candy Crush. It was anticipated that the challenge variety would reduce boredom, while the familiar interface could reduce cognitive load and thus reduce anxiety. The gameplay itself is similar to Brick Breaker (Wingfield, 2006), the aim is to make several lines of bubbles on the screen disappear by firing bubbles at them. The challenge comes in as the only way the player can eliminate the bubbles is to fire ones representing the correct answer to a maths question. A bubble generator with a cannon attached shows the questions to the players, for which they can switch between different questions, it is then up to the player to calculate the answer to those questions (the game encourages mental maths). The player then aims a canon attached to the generator and fires a bubble at a set of stationery bubbles containing the correct answer. Maths problems come in the form of addition, subtraction, multiplication, division, powers and some basic algebra. If the player gets a question wrong then more stationery bubbles appear on screen, if too many bubbles fill the screen then the game is over. The game is not timed, however a red line lowers down the screen as players get more questions wrong giving the illusion of time running out. On this basis and from the literature (Ashcraft & Moore, 2009; Lee C Mann & Walshaw, 2019; Lee Coveny Mann, 2017) it was anticipated that participants would experience some mathematics anxiety due to this game mechanic.

Comparative analysis

The inclusion of the MARS before and after gameplay enabled the researcher to undertake a comparative analysis. They could investigate whether engagement with the mobile game had a significant impact on participants' levels of mathematics anxiety. Any disparities observed would yield valuable insights into the game's efficacy in alleviating or potentially exacerbating mathematics anxiety.

Research objectives

This study contributed to research objectives 3 and 4 *(Investigate the impact of games on mathematics anxiety in University of Sheffield student*s and *Identify game attributes that impact mathematics anxiety*)

4.4.3. Participants

Study 4 targeted students on courses involving some form of mathematics or statistics within the University of Sheffield. This was primarily due to the researcher being already located at this institution, participants would be quicker and easier to access. Additionally, students at the University of Sheffield consist of a diverse range of students from different backgrounds and subject areas, making it possible to compare mathematics anxiety and the effects of the educational computer games amongst a variety of different demographics.

Justification for participants

Convenience sampling was chosen due to accessibility and the exploratory nature of the study. This approach is widely used in early evaluations of educational technologies where specific populations are hard to randomise (Etikan et al., 2016). Recruitment across multiple departments reduced disciplinary bias, as previous work shows that mathematics anxiety varies between STEM and non-STEM students (Núñez-Peña et al., 2013). While self-selection may introduce bias, similar studies have demonstrated that volunteer samples still yield valid insights into affective responses to educational games (Fortin et al., 2013). The sampling strategy is therefore consistent with existing practice for preliminary intervention research.

4.4.3.1. Sample composition

Highlighting the study's approach, it is essential to underscore that this research adopted a mixed-methods strategy. The principal objective of this study was to develop the fishbone model, which elucidates the underlying causes of fluctuations in mathematics anxiety among university students who engage in browser games. It is important to note that as the fishbone model is a qualitative tool to identify potential causes of issues with previous research, demonstrating it does not require empirical testing (Deri et al., 2020; Sakdiyah et al., 2022) as part of this PhD research.

The challenge of obtaining a representative sample became evident with the participation of just over 100 students in the 5-minute everyday mathematics questionnaire (Study 2). Given that most students were either on holiday or returning home after exams, achieving a representative sample posed a significant challenge. These figures shed light on the formidable task of attaining sample sizes of 3%, 5%, or even 10%, which would have required a sample size approaching or exceeding 100 students, a practical impossibility given the lack of students at the time. Thus, the tables clearly demonstrate the limitations of generalisability due to the substantial sample sizes required.

Instead, Table 7 overleaf presents the typical sample sizes recommended for games user research and general user research studies, which generally revolve around 12. These smaller sample sizes underscore the qualitative nature of the study and the acknowledgment that the data collected was not intended for generalisation:

Table 7: Sample sizes and gameplay times for qualitative user research studies

Citation	Timeframe	Sample size
Bruggers et al. (2018)	1 day intervention 30mins	12
Laitinen, (2005).	Until game is complete (over a week).	3 (usability experts)
Saridaki et. al.. (2009)	10 hours in 5 school days	12
Whitton, N. (2007).	N/A	12 participants, 30 minute interviews, equal number of male/female participants. All age groups, 20-29 to 60 years
Tobii Pro (2020)	N/A	Several rounds of testing, with less than 10 participants.
Hwang, & Salvendy (2010)	N/A	10 +-2 Comparison of the literature.
Reichlin, et. al (2011)	6 months	13 participants across 4 different sessions
Loop11 (2012)	N/A	5-20 participants for qualitative studies
Kelkar (2018)	N/A	Five is enough, if you want to only identify significant (obvious) usability issues ("big rocks"), those that have a 31% or higher chance of occurring with at least one participant Most common is about 9 participants, big rocks with 20% or higher chance of occurring with at least one participant..

4.4.3.2. Measuring mathematics anxiety

It is also true that some studies using qualitative methods to analyse mathematics anxiety do not include a mathematics anxiety scale (Puteh, 2002; Stubblefield, 2006) but rather the studies rely on interviews and classroom observations of students to delve into student perceptions of mathematics anxiety and its causes.

That said, the 30-item mathematics anxiety scale was still worth including as a tool in qualitative study to allow participants to reflect on their scores, and to determine how well the scores reflect their own perceptions of their mathematics anxiety levels when playing the game. This is a similar approach used for alternative psychological measures such as wellness and general competency assessment (de Peralta et al., 2017; Prochaska, 2003; Locke, Myers, & Herr, 2001).

4.4.4. Use of the shortened MARS scale

The selection of the shortened MARS questionnaire instead of other scales, such as Gabriel et al.'s Mathematical self-efficacy and anxiety questionnaire (MSEAQ) (May, 2009), was driven by its specific advantages in measuring mathematics anxiety effectively in the targeted demographic. The shortened MARS offers a validated and reliable structure specifically tailored to university students, ensuring accuracy in capturing anxiety levels while minimising participant fatigue. This focus on brevity was critical given the study's integration of multiple methods, such as eye-tracking and diary studies, which demanded participant stamina and engagement.

In contrast, while the MSEAQ provides insight into self-efficacy alongside anxiety. It emphasises different constructs that do not align directly with the study's objectives, which center on anxiety reduction through gaming interventions. This decision aligns with prior studies (e.g., Suinn & Winston, 2003) that have successfully employed the MARS in similar contexts for its precision and clarity in measuring mathematics-related anxiety.

4.4.5. Participant recruitment

In terms of where precisely to access potential participants. Students were recruited via the University of Sheffield student volunteer list. In the recruitment email, students were asked to apply if they were studying a course that contains some mathematics. The UOS's Math and Statistics Help service (MASH) were also approached and asked to help promote the study by placing posters with information about the research and where to register on the walls of MASH's office. The poster contained a QR code with a link to the registration form for the study as well as the researcher's email address so potential participants could contact the researcher for more information. Furthermore, MASH was carrying out their own mathematics anxiety research at the time. They ran a study which had some methodological similarities, but used workshops, online testing, and 1:1 session, rather than games as interventions (Marshall et al., 2017). This seemed to be an ideal time to promote this researcher's own study, while MASH (through events and advertising) were making students more aware of mathematics anxiety and how it affects them in their everyday lives.

Another concern is the degree to which other activities outside of the study influence mathematics anxiety levels during the period of data collection. There are already numerous external factors that increase mathematics anxiety: in education in particular, reliance on rote memorisation and recitation, personal embarrassment from failure, teachers who may come off as uncaring towards student needs, as well as negative attitudes towards mathematics amongst peers (Marshall, E., Mann. V., & Wilson, 2016). Hence in the diary study, the question of "Did you do any mathematics outside of the game today" is included. The researcher could then compare mathematics anxiety levels of participants doing maths outside of the game (e.g. for exams) to observe any trends and effects on their anxiety playing the game.

4.5. Ethical implications

While no part of this research should harm the participant, however, due to participants potentially being exposed to anxiety through playing the game or simply being on a computer, there could therefore be psychological distress and discomfort. To minimise any risk of harm, the risk of participating was stated in the consent form. The participants data was anonymised, there was no attempt to deceive the participants throughout the process. Additionally, participants were given the right to withdraw from the study at any time.

As a requirement, each stage of this study (Study 1 to Study 4) had ethics applications approved to carry out data collection and analysis. Furthermore, due to the handling of personal information for Study 2, a separate section on ethics implications was added to the Study 2 of the methodology chapter. Details of the steps taken to minimise harm to participants are detailed below.

4.5.1. Voluntary participation

Students were recruited via email using the University of Sheffield’s volunteer list. The email informed readers of the details of the data collection process, the potential reward of a £20 Amazon vouchers should they choose to take part, and what would happen to their data once the data collection was complete. At no point was any force used to encourage students to sign up. Participants were allowed to drop out of the study at any time they felt necessary. Furthermore, they did not have to give a reason for leaving. This was stated in the consent form, which participants were asked to read to sign before moving on the demographic questionnaire.

4.5.2. Informed consent

Participants were informed in written form and verbally. At the start of the study, participants were emailed a Google form containing the purpose of the study, the data collection procedure, the potential benefits and risks of participation, how data would be handled post-data collection, and what participants if they want to complain about the research. This was provided along with the contact details of the researcher encouraging participants to ask the researcher questions about the study if they had any. The details were written in a way that participants of this particular demographic (i.e. university students) would understand. Participants were also asked to sign the form to confirm that they had read the information sheet and agree to the terms of the study. During the usability lab tests, just before data collection commenced, participants were reminded verbally of the details of the consent form they had signed to confirm they understood what the research required of them and to emphasise that they were free to withdraw at any time.

4.5.3. Anonymity and confidentiality

While it is a possibility that participants could be harmed due to less sensitive data collection approaches, participants could be damaged from how their data is handled and shared, particularly if sensitive information is not treated confidentially, particularly apparent given the study involves collect personal demographic data, anxiety levels, and personal activities they take part in which involve mathematics. As such, the study falls into the scope of GDPR, personal data defined as “data that relates to living people from which they can be directly or indirectly identified” (UKRI, 2020). On the one hand, this has the advantage that data can be kept indefinitely along as it is used for historical research purposes (ICO, 2020). In this case, it is planned to turn this research into several papers after submission, meaning data would be needed for up to 5 years, and this was stated in the information sheet. To avoid participants being identified in the study, their names were replaced with 5-digit participant ID's (e.g. 00001, 00002). These ID's were referred to throughout the study.

4.5.4. Deceptive practices

No part of the study involved covert research, meaning the identity of the observer and the purpose of the research was known to the participant throughout the study. This was through emailing details of the research process and consent form to potential participants at the beginning of the study, reminding them of the remaining part of the process during the usability lab sessions and also answering any questions they had in relation to data collection, storage and processing.

4.5.5. Right to withdraw

Given the literature on mathematics anxiety present cases of performance anxiety (Ashcraft & Moore, 2009), it was anticipated that some students might feel anxious having their performance in maths watched and recorded, particularly in a more clinical setting with numerous wall camera's such as the usability lab. All participants were notified that they had the right to withdraw at any stage of the process and that the aim was not to assess their performance in maths but their behaviour while interacting with the game. This was communicated via the student volunteer list and consent form prior to taking part, as well as during face to face lab sessions. Furthermore, they were not coerced or pressured into staying on if they did decide to withdraw from the study.

4.6. Participant educational background and impact on mathematics anxiety

The original plan for this study was to recruit social science students due to anticipated high levels of mathematics anxiety which would have made it clearer to see the effects of the game. Many students in the social sciences (such as economics and psychology) are required to take statistics courses to progress through the curriculum conflicting with their intention of avoiding mathematics related subjects (Ali & Iqbal, 2012; Zeidner, 1991). However, from Study 1, 3, it was clear the sample size would not be large enough, as not enough participants were taking part. Furthermore, other studies like Núñez-Peña et al. (2013) compared students across departments, indicating it was easier to recruit this way, and also provided the opportunity to compare students from all disciplines with other studies taking the same approach.

From the literature, students with social science and humanities backgrounds prior to starting a social science course display higher levels of mathematics anxiety than students from science and technological backgrounds (Núñez-Peña et al., 2013). Additionally, students are more likely to have experienced poor mathematics teaching in school and have done little mathematics since their GCSEs, the lack of ongoing practice increasing mathematics anxiety further (Hunt et al., 2011; MacInnes, 2009).

Furthermore, pre-test mathematics anxiety data from the MASH study showed that social science students at the University of Sheffield had the highest mean mathematics anxiety score of all faculties at 28.1. This demonstrated that mathematics anxiety is most prevalent amongst University of Sheffield social science students.

4.7. Data collection

4.7.1. Demographic questionnaire

Participant demographic data can help explain any potential expected or unexpected results in the data. A demographic questionnaire was produced that gathered the age, gender, first language, nationality, degree level, course, last mathematics qualification of the participants (see Appendix G). These are all factors that have been previously shown to correlate with mathematics anxiety to some degree (Mutodi & Ngirande, 2014). The questionnaire also collected data on the frequency the participants played computer games in their daily lives, as well as whether they have previously played said games being used for data collection. Given that individuals with more computer experience are less likely to have mathematics anxiety (Gressard & Loyd, 1986; Suri et al., 2003), it may be the case that participants who play computer games more frequently are less likely to have mathematics anxiety too.

In the appendix, there are two versions of the questionnaire, one for Study 1 (see Appendix F), and another used for Study 3 and Study 4. The demographic questionnaires for Studies 3 and 4 have two alterations. Based on the feedback from the researchers' supervisors, one question was added as a follow up from querying the participant's highest mathematics qualification. This question asks when the participant completed the qualification. This particular question is important as studies have shown the longer people go without mathematics education the higher the mathematics anxiety levels (Helal et al., 2011). The question regarding what games students have played previously also changed to only include the game to be used in Study 4. The demographic questionnaire was given to participants prior to the MARS scale due to studies showing that demographic item response rates increase when provided to participants first, and without influencing response rates for non-demographic questionnaires (Teclaw et al., 2012).

4.7.2. MARS Brief UK

The questions in the original MARS Brief questionnaire are designed for US students. As the study was conducted on UK students, the following changes shown in table 8 were made to the MARS Brief:

Table 8: MARS Brief changes (US to UK terminology)

Changes made	Reasons for change
Changed the phrase ‘math’ to ‘mathematics’	While neither version of the term is incorrect, ‘math’ is favoured in the US and Canada while ‘mathematics’ is favoured in the UK, Australia and most other English-speaking countries.
Changed ‘Sales Tax’ to ‘VAT’	Sales tax is only used in the US, whereas VAT is used in the UK
Changed ‘$’ to ‘£’	GBP (£) is the currency used in the UK, USD ($) is used in the US.
Changed “pop quiz” to “mathematics quiz without warning”	Pop quiz is a term used widely in American schools but not so much in UK schools.

Participants were given the new MARS Brief UK questionnaire pre-test at the very start of the study and as a post-test questionnaire after playing the game. There was a 3-week time gap between the pre-test and post-test. This gave participants enough time to play the chosen game (Bubble Function - described in the next section) to completion. The time-gap also helped prevent participants being too familiar with the mathematics anxiety scale questions. Too much familiarity, and participants would begin to base answers on the memories of answers provided to the same questions for the pre-test. Further if participants become bored of the repetition from answering the same questions a second time, they would be less likely to complete the post-test scale (Streiner, Norman, & Cairney, 2014). Otherwise the post-test scales allow the researcher to reassess student mathematics anxiety levels after playing the game.

4.7.3. Diary studies

Diary studies are a qualitative research method that allows participants to record experiences of their daily lives or an activity they're participating in. They are regularly employed in usability studies (Flaherty, 2016), and used longitudinally, ranging from days to months or more. This makes them ideal for recording participant experience with the mathematics games in the 30 day period of the study. Diary studies do have the drawback of participants potentially forgetting to submit their entry for the day. To minimise missing entries participants were reminded each diary entry they submitted counted towards an entry for a £20 Amazon voucher at the end of the week. The diary study features several questions similar to the (Sohn et al., 2008) study on mobile information needs, but adapted to include three sections. The first section focuses on the games and participants' anxiety levels after playing, asking what time they played, and how many times they played that day. This allowed the researcher to examine if there is a relationship between the time spent playing a game and mathematics anxiety. Studies have already shown that the time spent can potentially affect emotions such as aggression (Williams & Skoric, 2003). The second section focuses on general anxiety during the day, asking participants how anxious they felt and why. The next question goes into everyday mathematics (similar to the Study 2 question in Appendix F) asking participants what activities they did involving mathematics, what mathematics took place. However, given this study involves measuring mathematics anxiety for this portion of the study participants were asked how anxious they felt carrying out these tasks and why they felt anxious. For these questions it was possible to pinpoint which everyday mathematics activities affected participant anxiety the most and identify whether the activities they undertook were the cause of anxiety change or the game itself.

1.1.1. Rationale for the 30-day diary period

The duration of the diary study was set at 30 days. This timeframe aligns with prior research on digital health and educational interventions, where month-long studies are common because they provide sufficient exposure for participants to adopt new behaviours and reflect on change while minimising dropout rates (Bruggers et al., 2018; Whitton, 2007). A 30-day period allowed participants to incorporate the game into their daily routines, progress through its levels and observe fluctuations in their mathematics anxiety over time. Shorter durations would risk capturing only initial reactions, whereas longer durations might reduce compliance.

4.7.4. Eye tracking

It is possible to identify threat signals, such as fear and anxiety through eye gaze. Little is known about eye reactions in relation to solving mathematics problems. However, one study did find a positive correlation between eye fixation and complexity of mathematics problems, with eye fixation increasing when an additional problem involved a carry operation (compared to without) (Green, Lemaire, & Dufau, 2007). Even fewer studies look at the eye movement trends in relation to mathematics anxiety. One study by Hunt, et.al. (2015) found a positive relationship between self-reported mathematics anxiety levels and response time when faced with mathematics problems. More specifically, the study identified increases in specific digit fixations, saccades (small, rapid eye movement towards a point of interest) regressions and dwell time, all factors that predicted response time. The hardware used was the Eyelink 1000, a desktop eye tracker suitable for all age groups from infants to the elderly. Initially the eye tracker had issues picking up eye movement from participants with glasses, however once collaboration had been performed several times, eye movement was more accurate. Based on previous study, it was predicted that higher the participant's mathematics anxiety levels, the longer response time when encountering mathematics problems in the game.

4.8. Study 4 research recordings

The table below presents a summary of the audio and video footage recorded for Study 4. The study involves 17 participants who were each recorded for audio interviews, gameplay observations, and eye tracking footage. The table provides the average time per participant for each type of footage, as well as the total time for all 17 participants. Additionally, the typical file size for each type of footage is presented, along with the estimated total data size for all the recordings. This information is useful in determining the amount of data that will need to be stored and analyzed for the study, as well as the time required for data processing and analysis. Overall, the table serves as a helpful reference for understanding the scope and scale of the data collection process in this research study.

Table 10: Study 4 - Data recording times and file sizes

Type of footage	Time per participant (min)	Total time for 17 participants (min)	Typical file size (MB)	Total data size for 17 participants (MB)
Audio interviews	9.8	166.6	13	221
Gameplay observations	10.4	176.8	137	2,329
Eye tracking	10.2	173.4	137	3,196
Total	-	516.8	-	5,746

In total, there was 516.8 minutes (or 8.6 hours) of footage recorded, and the total data size for all the recordings would be approximately 5.7 gigabytes.

5. Study 1, 2, 3 results

The chapter contains the results for Studies 1, 2, and 3. Note that sample sizes across the four studies varied considerably:

Study 1 (usability pilot) involved 5 participants. Study 2 (cross-sectional survey) analysed data from 125 students after removing one incomplete response. Study 3 (mobile game feasibility study) included 5 participants. Study 4 (main experiment) recruited 17 participants, of whom 13 completed both pre and post-intervention MARS questionnaires. These differences reflect the distinct aims and methods of each study and should be considered when interpreting the results and generalisability.

5.1. Study 1: Pilot part 1

5.1.1. Algebra Meltdown

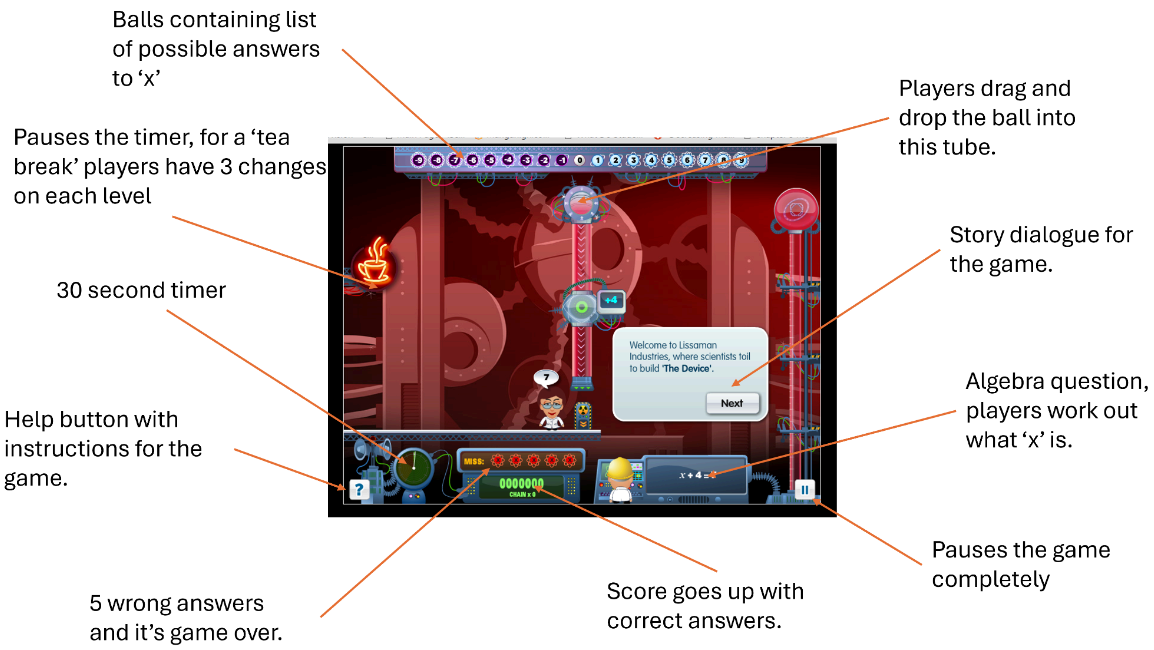

Figure 7: Algebra Meltdown game interface

Figure 7 shows the interface for Algebra Meltdown, highlighting key features of the game. In this game from Mangahigh, students control the ‘Nuclear Generator’. They are given an equation in the bottom left of the screen and must solve the problem to deliver the correct atom. Sending the wrong atom or taking too long results in the scientist becoming angry and leaving. Players have three "misses" before losing the game. Providing enough correct atoms fills the Power Gauge, allowing progression to the next shift, where equations become more difficult. The game offers multiple skill levels for continued practice and enjoyment in solving equations.

5.1.1.1. Game usability and participant experience

Algebra Meltdown was found to be generally engaging but participants struggled due to its timed nature and complex questions. Participants encountered usability issues with the game's drag-and-drop mechanics and had difficulty understanding the instructions. For instance, one participant mentioned struggling with the controls because they did not thoroughly read the instructions. The game’s interface was sometimes confusing, particularly when dragging and dropping answers into the generator, which occasionally did not work as expected. Despite these challenges, participants felt motivated by the game's feedback and reward system, finding it fun and engaging once they understood the mechanics.

One significant usability error involved the arrow indicating where to drag and drop answers, which was often misunderstood. Participants clicked on parts of the generator or screen that did not respond as expected, causing frustration and time delays. Furthermore, participants often skipped through the instructional dialogue boxes too quickly, leading to confusion during gameplay. Additionally, the theme of the game, which involved nuclear physics, was found to be intimidating by some participants, making the mathematics questions seem more difficult than they actually were.

Despite these issues, there were positive aspects of Algebra Meltdown. Participants appreciated the progressive difficulty levels and the game's reward system, which kept them motivated. The graphics and sound effects also received positive feedback for making the game more engaging. Participants felt a sense of accomplishment when they managed to solve the complex problems, which was a significant confidence booster for some.

5.1.1.2. Mathematics anxiety

Algebra Meltdown produced mixed results regarding mathematics anxiety. Some participants experienced increased anxiety due to the game's speed and complex interface.

“Erm, when the speech bubbles went red, I started like shaking, because once that happens you're trying to think hard, but then it's like harder to think [laughs], when you're...then you feel like, under pressure” (Participant 5).

The pressure of timed tests and the need to answer quickly contributed to this anxiety. However, others felt more confident after overcoming challenges. Participants who managed to progress through the levels found the game boosted their confidence, especially when they succeeded in answering the more difficult questions. As one participant stated, *"It's like playing. And I felt safe because there was no grade at the end."* (Participant 2). The balance between anxiety and confidence seemed to depend on the individual's ability to navigate the game and understand its instructions.

Participants noted that while the game was stressful at times, it also provided a safe environment to practice mathematics without the fear of real-world consequences. This aspect was particularly beneficial for those who typically experience high anxiety in test situations. The combination of stress and reward helped some participants feel more prepared and less anxious about their mathematical abilities in general.

5.1.1.3. Replayability and participant preferences

When it came to replayability and participant preferences, Algebra Meltdown was preferred for its engaging context and challenging nature. Participants appreciated the storyline, distinctive appearance of characters, sound, and graphics, which made the game more immersive. However, it was criticised for causing anxiety and having a cluttered interface. The game's fast pace and complex instructions were significant drawbacks for some participants. Nonetheless, those who enjoyed the challenge found themselves motivated to keep playing, despite the initial anxiety.

Participants expressed a desire for more intuitive controls and clearer instructions to enhance the overall experience. They also suggested incorporating more relatable themes that would make the mathematics problems seem less daunting. One participant suggested, *"Maybe they need to use characters in other fields that are less threatening because like nuclear generator. I think for a person who doesn't like science in the first place would be put off."* (Participant 2). Despite its flaws, Algebra Meltdown's engaging elements and challenging nature made it a favourite among participants who enjoyed a more dynamic and stimulating learning environment.

5.1.1.4. Mouse clicks

In Algebra Meltdown, mouse click density varied significantly depending on the complexity of the questions and the participant's familiarity with the controls. Higher levels of mouse clicks were observed as participants became more confident with the game's mechanics, particularly during simpler questions that allowed for quicker interactions. Conversely, the lowest level of clicks occurred when participants faced more complex questions that required additional thought and time to solve . Notably, Participant 1 struggled initially with dragging and dropping atoms into the correct slots, leading to high mouse click density due to repeated attempts to place answers correctly. This difficulty was attributed to an expectation of keyboard input rather than mouse control . Participant 2 also experienced issues with unclear instructions and struggled with double-digit algebra questions on harder levels, resulting in a higher frequency of clicks as they attempted to understand and navigate the game . Generally, mouse click activity was steady but spiked when participants had to make quick decisions under time pressure, leading to anxious and panicky clicking.

5.1.1.5. Facial reactions

Participants showed varied facial reactions while playing Algebra Meltdown. Participant 1 had a stern expression and appeared more engaged and upright during the initial stages, but showed signs of boredom and fatigue as the session progressed. Participant 2 demonstrated a generally relaxed demeanor, leaning back in their chair, and occasionally smiled at the game's feedback. Participant 3 exhibited engagement throughout the session, with looks of confusion and surprise when errors occurred, and occasionally smiled at the game's animations. Participant 4 remained content throughout the session, finding the game fun and engaging despite initial struggles with the tutorial. Participant 5, on the other hand, appeared relaxed and content during easier questions but became visibly anxious during more complex stages.

These varying levels of expressiveness indicate that the FaceReader may not have accurately captured the internal emotions of participants, as less expressive individuals exhibited fewer visible expressions. The think-aloud data showed that even participants with no facial expression found the game fun or experienced increased anxiety, highlighting a discrepancy between facial expressions and verbal feedback.

5.1.2. Giving Change

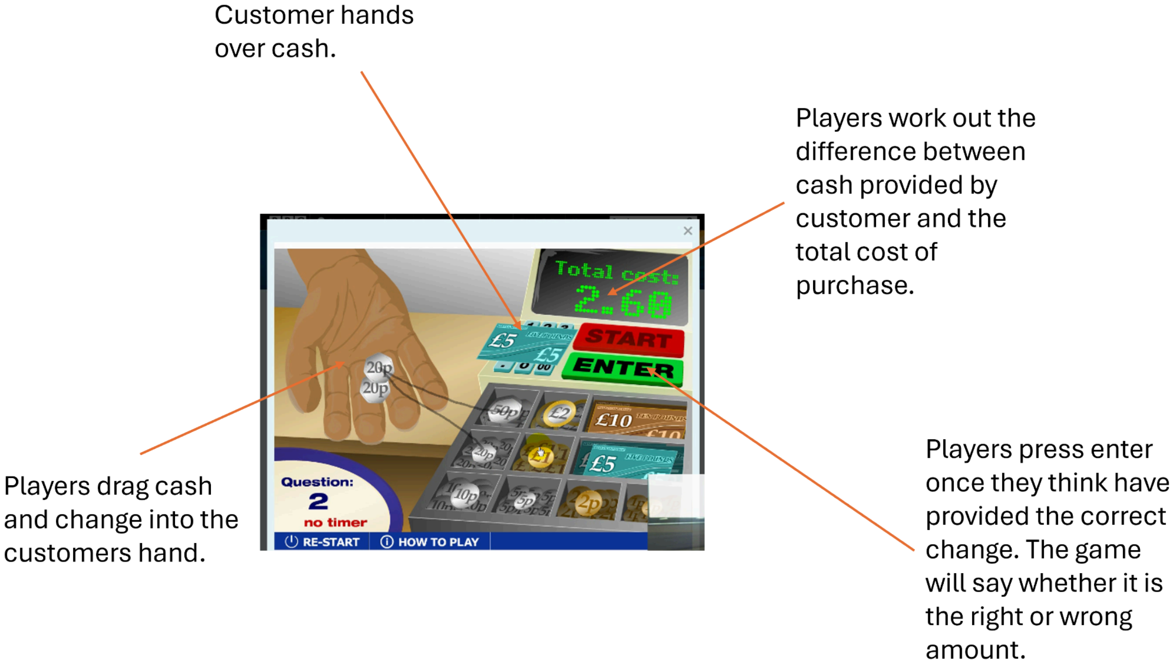

Figure 8: Giving change game interface

Figure 8 shows the interface for Giving Change, highlighting key features.This browser-based game is designed to help players practise giving the correct change in a retail setting. As a virtual shopkeeper, players receive cash from customers and must provide the appropriate change from the till. The game does not impose a timer, allowing players to work at their own pace. When an incorrect amount is given, the game simply indicates the error without penalty. The difficulty of the calculations varies randomly, providing a mix of both straightforward and challenging scenarios.

5.1.2.1. Game usability and participant experience

The Giving Change game was easier to use and had fewer usability issues. Participants appreciated the game's relatable story and the absence of a timer. The game involved practical scenarios like shopping, making it easier for participants to relate to and understand the tasks. The interface was straightforward, and the lack of time pressure allowed participants to focus on solving the problems without feeling rushed.

Participants found the feedback from the game to be clear and helpful. When they got answers wrong, the game provided immediate feedback, helping them understand their mistakes and learn from them. This aspect of the game significantly contributed to its ease of use and the overall positive experience of the participants. One participant noted, *"It's easier to use and I think because of the fun part of it like erm…I think in the first game I said I was anxious not to get things wrong. But in this one I erm…in some instances I did it badly did it wrong just to see what would happen what would I get. Yeh so it was all fun."* (Participant 2) The simplicity of the controls and the clarity of the objectives made the game accessible even to those who were not regular gamers.

The game's practicality was a significant advantage. Participants could easily see how the skills they were practising could be applied in real-life situations. This relevance made the game more engaging and meaningful, which in turn reduced anxiety and increased confidence. Participants felt that they were not just playing a game, but also acquiring useful skills that they could use outside the gaming context.

5.1.2.2. Mathematics anxiety

The Giving Change game mostly reduced anxiety due to its clear, feedback-driven, and non-timed nature. Participants felt less pressured compared to Algebra Meltdown because there was no timer to rush them. The practical application of the game's tasks, such as calculating change, made it more engaging and less intimidating. Participants mentioned feeling more confident in their mathematical abilities as they progressed through the game. The straightforward nature of the tasks and the immediate feedback helped build their confidence, as they could see their progress and understand their mistakes without the added pressure of a timed environment. One participant shared, *"The feedback was clear. It made a sound shows that you've given too much change and a message will come that was too much."* (Participant 2).

The game's design, which avoided complex and intimidating themes, further helped in reducing anxiety. By focusing on everyday scenarios, participants could relate to the tasks and felt more comfortable tackling the mathematical problems presented to them. This design choice was crucial in making the game more approachable and less anxiety-inducing.

"[laughs] Err, well it's, it's taken me back to memory lane, when I used to be at the till, till [inaudible], because I belong to a family of traders. So we used to sell, and that was changing money and payment […]" (Participant 4)

5.1.2.3. Replayability and participant preferences

Giving Change was preferred for its ease of use and practical application in real-life scenarios but was criticised for lacking depth and fun. While participants appreciated the game's practicality and clarity, they felt it did not offer the same level of engagement and excitement as Algebra Meltdown. The absence of a complex storyline and the simplicity of the tasks made the game less appealing for long-term play. However, its practical benefits and the confidence it instilled in participants made it a valuable tool for educational purposes.

Participants suggested that adding more levels and varying the difficulty of tasks could enhance the game's replayability. Additionally, incorporating more engaging elements, such as a storyline or more interactive features, could make the game more enjoyable. Despite these criticisms, the game's educational value and its ability to reduce mathematics anxiety were highly appreciated.

5.1.2.4. Game interaction

For the Giving Change game, peaks in mouse click density were observed when participants dragged coins to the customer's hand, often doing so rapidly and sometimes inaccurately, resulting in mistakes such as giving too much change . Slumps in mouse density occurred when participants took time to think through more complicated calculations or waited for animations to finish. Participant 1 found the game interface immediately comfortable but noted minor errors due to the close positioning of the Start and Enter buttons, which sometimes caused navigation issues . Participants generally found the game easy to use, with confidence boosted by the simplicity and clarity of feedback when correct answers were provided. However, the lack of characters and depth in the storyline made the game less engaging, with some participants considering it more suitable for job training rather than a fun activity . Anxiety levels were mainly affected by the difficulty of questions and concerns about giving the wrong change, particularly under time constraints.

5.1.2.5. Facial reactions

For the Giving Change game, Participant 1 initially appeared content, with some smiles, but displayed signs of boredom and fatigue towards the end. Participant 2 was much more relaxed compared to Algebra Meltdown, showing contentment and occasional smiles at the game's feedback. Participant 3 showed mild enthusiasm, with some laughter when getting questions wrong, but did not find the game particularly fun. Participant 4 appeared relaxed and focused, with occasional smiles, and mentioned in the interview that the game boosted their confidence significantly. Participant 5 exhibited a relaxed demeanor initially but occasionally displayed boredom and turned to the observation window, indicating they had finished playing early.

Again the differences in expressiveness suggest that the FaceReader might not fully capture the participants' internal emotions, especially for those who are less expressive. Think-aloud data revealed that participants found the game enjoyable but repetitive, regardless of their facial expressions.

5.1.3. Ordering Fractions

Figure 9 shows the interface for Ordering Fractions, highlighting key features of the game.This browser-based game challenges players to order fractions in ascending order. To achieve this, players convert the fractions into regular numbers before arranging them. After ordering the fractions, players press a "Check" button to verify their sequence. If the fractions are ordered incorrectly, the player loses a life. The game ends when all five lives are lost. While the difficulty of the tasks varies, the game is not timed, allowing players to progress at their own pace.

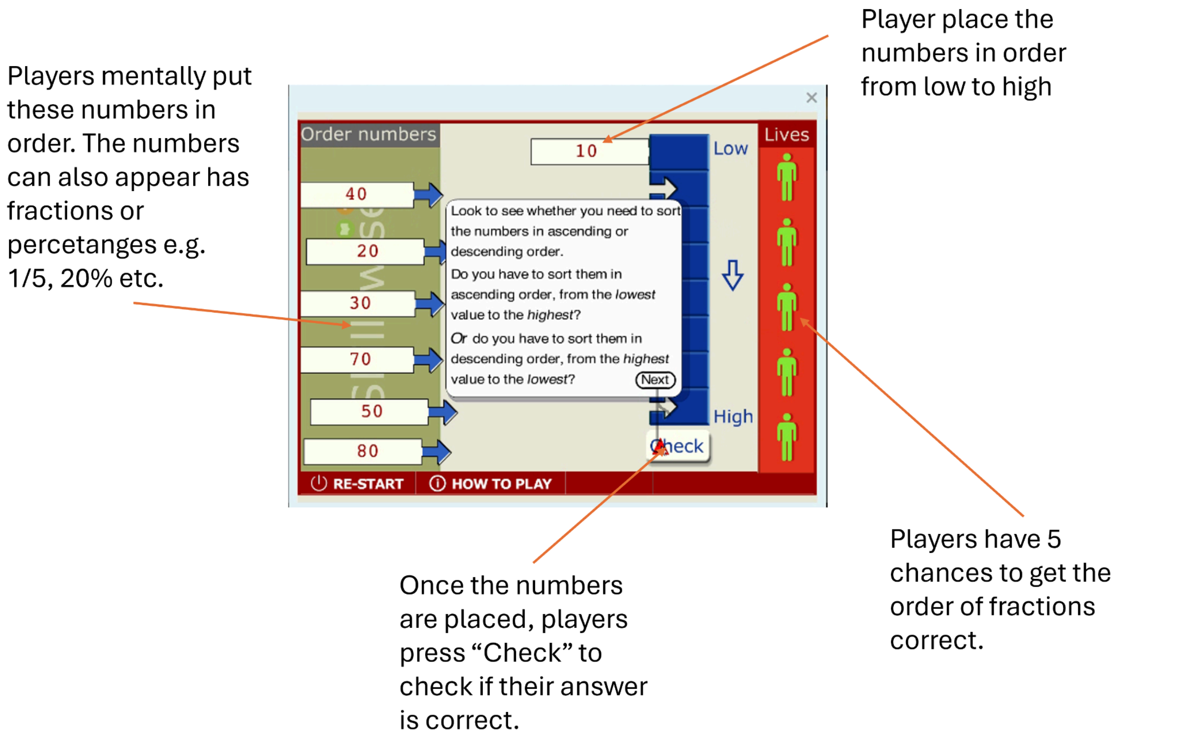

Figure 9: Ordering Fractions game interface

5.1.3.1. Game usability and participant experience

Ordering Fractions was considered boring and repetitive by most participants due to the lack of sound, story, and engaging elements.

“Like before, it’s a boring game [laughs]. It doesn’t boost your motivation to go further for the err. And then, I don’t think, there’s err, like sound, err…” (Participant 4)

It was easy to use, and was seen as a useful practice tool by some. The game’s interface was simple and straightforward, which made it easy to navigate, but this simplicity also contributed to its lack of engagement. Participants felt that the game did not offer enough variety or challenge to keep them interested.

The absence of sound and engaging elements made the game feel more like a repetitive exercise than an interactive experience. Participants quickly grew bored with the tasks, as there was little to motivate them to continue playing. Despite these criticisms, the game was effective as a practice tool for those looking to improve their skills in ordering fractions. The simplicity and clarity of the tasks made it a useful resource for reinforcing basic mathematical concepts.

Participants mentioned that the game felt more like an online tutorial than a game. This perception was primarily due to the repetitive nature of the tasks and the lack of engaging elements. While the game was effective in helping participants practice and reinforce their skills, it failed to keep them engaged and motivated over longer periods.

5.1.3.2. Mathematics anxiety

Ordering Fractions generally did not impact anxiety levels significantly but was perceived as a useful practice tool for some. The lack of time pressure and the straightforward nature of the tasks meant that participants did not feel particularly anxious while playing the game. However, the game also did not offer much in the way of building confidence, as it lacked the engaging elements that made other games more motivating. Participants who were already comfortable with the material found the game easy and unchallenging, which limited its effectiveness in reducing anxiety.

The game’s design, which focused solely on ordering fractions without incorporating more dynamic and interactive elements, limited its ability to reduce anxiety. Participants felt that while the game was useful for practice, it did not provide the same confidence boost that more engaging and challenging games could offer. This lack of engagement and motivation was a significant drawback.

5.1.3.3. Mouse clicks and game reactions

The Ordering Fractions game showed different patterns in mouse click activity. Peaks in mouse density occurred mainly during interactions with the tutorial and instructional videos, where participants often clicked repeatedly due to not noticing the "Next" button or other necessary controls. Dips in mouse density were attributed to participants taking time to read instructions or think through answers. Participant 1, for instance, fell asleep during the game, leading to random and repeated clicks . This game was generally considered easy to use, with confidence levels boosted by the straightforward nature of the tasks. However, the lack of sound, storyline, and engaging graphics made it less interesting, resulting in most participants not wanting to play the game again . The game's repetitiveness and simple interface led to a generally steady but unenthusiastic pattern of mouse click activity, with participants often completing tasks quickly and with little variation in their clicking patterns .

5.1.3.4. Facial reactions

The Ordering Fractions game elicited relatively neutral facial reactions. Participant 1 had a stern expression, appeared drowsy, and even fell asleep at one point, indicating boredom and lack of engagement. Participant 2 maintained a solemn expression, finding the game tedious due to the lack of storyline and context. Participant 3 leaned towards the screen, showing focus, but found the game repetitive and unengaging. Participant 4 was content despite struggles with the tutorial, finding the game relaxing and confidence-boosting. Participant 5, however, showed signs of boredom early on and did not find the game engaging.

5.1.3.5. Replayability and participant preferences

Ordering Fractions was the least preferred due to its repetitive nature and lack of engaging elements. Participants felt that the game was easy to use but did not offer enough variety or challenge to keep them interested.

“Yeh, it's the same game, because it's, it's just a remove, it's the same order for each level, it's just err, err, change the, change the numbers I need to fill in, but it the same order. If I do it two, or twice or third times I can remember the orders [laughs].” (Participant 3)

The lack of sound and story made the game feel monotonous, and most participants stated they would not consider playing it again. Despite its shortcomings, the game was recognised as a useful tool for practising and reinforcing basic mathematical concepts, making it a valuable resource for educational purposes.

Participants suggested that adding more engaging elements, such as a storyline, sound effects, and varying difficulty levels, could improve the game's appeal. They also noted that while the game was effective for practice, it needed more interactive and dynamic features to make it enjoyable and motivating. These improvements could enhance the game's replayability and effectiveness in reducing mathematics anxiety.

5.1.4. Summary

Algebra Meltdown was engaging but presented usability challenges, particularly with its timed nature, complex questions, and drag-and-drop mechanics, causing some participants to experience increased anxiety. However, the progressive difficulty levels, feedback system, and graphics were appreciated, boosting confidence in some players.

In contrast, Giving Change, which involved practical, relatable scenarios without time pressure, was easier to use and reduced anxiety significantly, though it was criticized for lacking depth and excitement.

Ordering Fractions, the least favored, was found boring and repetitive due to its simplicity and lack of engaging elements, serving mainly as a practice tool without significantly impacting anxiety. Participants across all games suggested improvements in controls, instructions, and thematic elements to enhance overall engagement and effectiveness.

The facial reaction data from Study 1 indicated that participant engagement with the games was influenced by their natural levels of expressiveness. Less expressive participants exhibited fewer visible expressions, while more expressive participants showed a broader range of emotions. As a result, the FaceReader might not have fully captured the internal emotional states of all participants, particularly those who are less expressive by nature. This suggests that while facial recognition technology can provide some insights, it may not always be a reliable indicator of internal emotions. The think-aloud data further supported this, showing that participants found the games fun or anxiety-inducing even if they displayed no corresponding facial expressions, highlighting the need for complementary methods to assess engagement and emotional response in educational games.

In terms of its contribution to the research aims, Study 1 identified the value of using everyday scenarios in maths anxiety games, as well as the importance of game user interface, mechanics, mathematics problem presentation, and difficulty levels.

5.2. Study 2: Everyday mathematics results

This study investigates the everyday mathematical activities of students, emphasising demographic differences and the most common activities involving mathematics. The key activities are analysed and compared across various demographic groups.

5.2.1. Demographics

5.2.1.1. Age groups

The majority of the 125 participants in this study were aged between 18-24 years, comprising 75 students (60.3%), with the next largest group being those aged 25-34, comprising 38 students (30.2%). This sample is reflective of the wider population at the University of Sheffield, where the majority of students are 24 or under.

5.2.1.2. Gender

Female participants were the majority across all age groups and made up 84 (66.7%) of participants, except for the 55+ demographic, where there was an equal split between one male and one female participant.

5.2.1.3. Level of study

In terms of study level, precisely 50.0% (63) of participants were undergraduates, with 33 postgraduate research and 30 taught students making up 26.2% and 23.8% respectively. The majority of students were full-time with 107 (84.9%) based on campus. Regarding accommodation, 47 students (42%) lived in house or flat shares, while 39 students (34.8%) resided in student halls. 26 students (23.2%) of participants were living at home.

5.2.2. Everyday mathematics activities

Twenty five categories of everyday activities involving mathematics were identified. Among these, shopping emerged as the most prevalent activity, accounting for 25.2% of the total activities reported. Managing personal finances followed closely, representing 20.3% of the activities. Other significant activities included planning events (9.3%), cooking (7.4%), and splitting the bill (5.1%). An analysis by age group revealed that students aged 18-24 were most frequently involved in shopping, whereas those aged 25-34 were more focused on managing their finances.

5.2.2.1. Activity analysis by demographics

Gender differences were apparent in the types of activities performed. Female students were more engaged in shopping, with 38.7% reporting this activity, compared to 24.2% who were involved in managing finances. In contrast, male students showed an equal distribution between shopping and managing finances, each constituting 30.8% of their activities. When considering the academic level, undergraduates led in shopping activities, with 48.8% of them participating in this activity. Meanwhile, managing personal finances was most common among postgraduate research students, with 40% of them engaging in this activity.

5.2.2.2. Mathematics topics and activities

The most frequently encountered mathematics topic across all activities was arithmetic, which was used in 73% of the reported activities. This was particularly evident in shopping and managing personal finances. Other mathematical topics, such as statistics and fractions, (used in shopping, managing personal finance, and studying) were used less frequently, reflecting the nature of the activities students were engaged in.

Table 11: Frequencies of mathematics topic show in mathematics activities

Activity	Mathematics topic							
	Arithmetic	Statistics	Geometry	Fractions	Estimation	Calculating time	Unit conversion	Total
Shopping	25	8	0	2	1	0	1	37
Managing Personal Finances	22	1	0	1	2	0	1	27
Cooking	7	0	0	2	0	0	0	9
Planning events	9	1	0	0	0	1	1	12
Gaming	5	0	0	0	0	0	0	5
Splitting the bill	7	0	0	0	0	0	0	7
Exercising	5	0	0	0	0	1	0	6
Studying	3	1	0	1	0	0	0	5

5.2.2.3. Detailed activity insights

This section provides insights into the everyday mathematical activities encountered by university students, highlighting how common tasks such as shopping, managing finances, and planning events involve the practical application of arithmetic, percentages, and other mathematical concepts.The activities discussed were adapted from the Bishop (1988) study on mathematics education in its cultural context. In the current everyday mathematics study, a new activity was identified, namely gaming, which highlights the evolving nature of how students engage with mathematics in their daily lives.

Shopping

Shopping was identified as the most common mathematical activity. It involved sub-activities like comparing items, calculating discounts, and general food shopping, primarily taking place in supermarkets. The mathematical concepts used in these activities included arithmetic, percentages, and fractions. The majority of shopping activities were reported by students aged 18-24, with 50% of them engaging in comparing items and prices. Females were particularly active in this category, representing 87.5% of the shopping demographic.

Managing personal finances

Managing personal finances was the second most common activity, with a strong emphasis on reviewing finances, such as checking balances and expenditures, which accounted for 77% of the reported activities. The 25-34 age group was the most active in this area, with 53% of them involved in managing their finances. Gender differences were also noted, with 82% of female participants engaged in reviewing finances, compared to 67% of males.

Planning events

Planning events, which ranged from holiday planning to organising daily activities, was another key area where mathematics was utilised. This activity often involved arithmetic, particularly in budgeting and time calculations. Students aged 18-24 were the most frequent participants in planning events, particularly in travel planning, which accounted for 33% of their activities. Female students were more likely to be involved in planning events, particularly travel planning, which was also common across all study levels.

Cooking

Cooking, although less frequent, involved mathematical activities such as rescaling recipes, which required the use of arithmetic and ratios. This activity was predominantly reported by students aged 18-24, with females leading in this category. Similarly, splitting the bill was a common activity that involved arithmetic, particularly division and subtraction. This activity was mostly reported by students aged 18-34, with females again being more active in this category.

Gaming

Gaming was another activity where mathematics played a role, particularly in calculating in-game metrics. Most of the gaming activities were reported by students aged 18-24, with males predominantly engaged in computer games.

Lastly, exercising, although less common, involved mathematical activities such as calculating time and repetitions, particularly in swimming. This activity was mainly reported by students aged 18-24 and 35-44, with a slight gender difference observed in the types of exercise.

Gaming aligns is an important new element of the 'Playing' theme of Bishop's (1988) everyday mathematics study (see Figure 13) and highlights the use of mathematical concepts in non-traditional, leisure contexts. This category is linked to the fishbone model as it demonstrates how embedding familiar, engaging activities like gaming into educational frameworks can help reduce anxiety by making mathematical concepts more relatable and less intimidating.

5.2.3. New adapted Bishop model category - Predicting

Additionally through the analysis of the above themes and the activities they involved, a new category, Predicting, was identified. This category captures activities where students engage in forecasting outcomes based on available data, such as planning events/gathering, estimating price, or gambling. Table 13 provides examples of mathematics activities and the corresponding mathematical topics associated with these everyday applications.

5.2.4. Relationship between Study 1 and 2

Study 1 (Games Usability Study) and Study 2 (Everyday Mathematics Study) are connected through their focus on applied mathematics and the use of context to make abstract concepts more concrete. Study 2 identifies everyday activities, such as shopping and managing finances, where students naturally apply mathematics in real-world scenarios. These insights strengthen the argument for games with real world themes in Study 1, which examines how educational games can reduce mathematics anxiety by presenting mathematical concepts in familiar, relatable contexts. Both studies highlight the importance of context in transforming abstract mathematics into tangible, confidence-building experiences for students.

5.2.5. Connection to the fishbone model

The insights gained from the "Everyday Mathematics Study" about students' everyday mathematical activities can inform the design of these games, making them more relatable and effective in reducing anxiety.

The "Everyday Mathematics Study" highlighted activities such as shopping and managing personal finances, which are common and involve arithmetic. By integrating these everyday contexts into the design of maths games, developers can create more relatable and less intimidating learning experiences, as suggested by the fishbone model (see section 6.1.4 ‘Game attributes that impact mathematics anxiety’). This approach could help to mitigate the impact of personal attributes, such as prior negative experiences with mathematics, on students' anxiety levels.

5.2.6. Summary of study 2

In conclusion, arithmetic emerged as the most common mathematical topic among students, particularly in activities such as shopping and managing personal finances. These activities often involved comparing prices and reviewing finances, reflecting the practical use of mathematics in daily life. The insights from this study suggest opportunities for integrating these everyday activities into educational games.

In terms of this study's contribution to the Fishbone Model: Study 2 identifies real-life contexts and activities involving mathematics, contributing to the environment and usage factors in the fishbone model.

Additionally, Study 2 informed the design of educational games by integrating everyday mathematical activities into the game scenarios and provided context for understanding the results of Study 4.

5.3. Study 3

5.3.1. Introduction

The aims of this study were twofold:

1) To evaluate the feasibility and functional suitability of the mobile game for implementation in Study 4.

2) To assess the clarity, comprehensibility, and overall usability of the MARS questionnaire to ensure its appropriateness for participants in Study 4.

5.4. Demographics

The participants in this Study 3 differed from those in Study 1: Pilot Part 1, primarily because several participants from the previous study had graduated and were no longer available. All participants in this study were aged between 25-34, were PhD students, and none had previously played Star Dash Studio. The following table summarises the demographic details, including their courses:

Table 12: Study 3 demographics

Attribute	Participant number				
	Participant 1	Participant 2	Participant 3	Participant 4	Participant 5
Latest mathematics qualification	UG	GCSE	UG	UG	UG
Course completed	3 to 4 years ago	5+ years ago	3 to 4 years ago	5+ years ago	5+ years ago
Computer game play frequency	Occasionally	Occasionally	Occasionally	Occasionally	Occasionally
Previously played games Star Dash Studios?	No	No	No	No	No

5.5. Summary of Study 3 results

5.5.1. Feedback on Star Dash Studio

Participants had mixed feedback on the game. One common issue was the long loading time, and several participants mentioned that the game's story either went unnoticed or was difficult to understand. Some tasks felt disconnected from the overall game narrative. For example, running through streets to collect gold coins, prompting participants to ask, “Where’s the maths?”. The fast pace of this section, combined with the requirement to restart the level after mistakes, was viewed as repetitive and demotivating.

For the mathematics side quests, participants reported that some tasks were unclear or unrealistic, such as a scenario where applying makeup was said to take 13 hours. They preferred “easy maths” involving basic arithmetic but felt anxious when faced with more complex tasks, particularly algebra. This anxiety was heightened by unclear instructions and the fast-paced gameplay in certain sections.

Participants also found the lack of guidance on essential controls such as jumping and sliding to avoid obstacles frustrating. The game’s visual design received mixed responses: some participants liked the graphics, while others disliked elements such as the character’s oversized hair and the confusing colour changes during bonus collection.

When discussing the game's impact on mathematics anxiety, most participants said the game had no effect or slightly increased their anxiety. In two sessions, the sound cut out, and one participant reported that this heightened their anxiety due to the missing audio feedback. When asked whether they would play the game again, responses ranged from “maybe if bored” to a clear “No,” with participants citing the game’s repetitive nature and the lack of perceived improvement in their mathematics skills.

5.5.2. Feasibility of the MARS Brief Questionnaire

Participants did not report any problems understanding or completing the amended MARS Brief questionnaire. They completed it both before and after playing the game. As the purpose of this stage was to identify any issues with the revised questionnaire rather than analyse the scores, the results are not reported here.

5.6. Changes for Study 4

Feedback on the game meant it was not a candidate for study 4, as explained above.

Feedback on the amended MARS Brief and demographics questionnaires. The changes are outlined in section 1.15.1 Demographics Questionnaire, and the Table 2 MARS Brief changes (US to UK terminology). None of the participants encountered any difficulties or confusion when responding to the modified questions in either questionnaire. As a result, both the amended MARS Brief and the updated demographics questionnaire were confirmed as appropriate and were subsequently used in Study 4.

6. Study 4 results

Study 4 addresses the primary research aim: to identify core educational game attributes that impact mathematics anxiety in university students. The study was designed with the following objectives:

1. To investigate the impact of an educational computer game (Bubble Function) on participants' mathematics anxiety.
2. To identify the game attributes that influence mathematics anxiety.
3. To develop a fishbone (cause-and-effect) model explaining the factors that contribute to fluctuations in mathematics anxiety during gameplay.

6.1.1. Demographic overview

The demographics of participants (age, gender, nationality, study level, etc.) were analysed to understand how different student groups experience mathematics anxiety in the context of educational games. It should be noted that the small sample size means results cannot be generalised to the whole university. However, it is useful to compare trends within the sample to understand types of students who would volunteer to take part in the study.

6.1.1.1. Age distribution

52.9% of participants were aged 25-34, while 41.2% were 18-24 years old. This differs from the broader university population, where most students are under 24. The higher proportion of older participants can be explained by the fact that 41.2% of participants were PhD students, who had been informed about the study earlier and had stronger motivations to participate.

6.1.1.2. Gender distribution

The majority of participants were female (52.9%), with 41.2% being male, and 5.9% identifying as non-binary. These percentages closely reflect the gender distribution of the general student population.

6.1.1.3. Nationality

Nine different nationalities participated in the study out of the 17 participants. The largest group of participants were British, with 9 participants making up 52.9% of the sample. Each other nationality was represented by one participant. This distribution slightly differed from the overall university population, where Chinese nationals typically make up the highest proportion of international students. Statistical analysis by nationality is not included, because all nationalities except British were only represented by one participant.

Given this uneven representation, any statistical comparison across nationalities would be unreliable. With only a single participant representing each non-British nationality, the data cannot capture within-group variation, and conclusions about nationality-based differences in mathematics anxiety would be speculative at best. Caution is therefore warranted when interpreting nationality findings, and future research should recruit larger, more balanced international cohorts to enable meaningful cross-cultural analysis.

6.1.1.4. Subject and faculty

As shown in Figure 15A, students came from four faculties: Social Science, Engineering, Medicine, and Science. Most participants came from the Information School. This perhaps reflected the researcher's close ties to this cohort. Research conducted by the Mathematics and Statistics Help (MASH) service at the University of Sheffield revealed that students from social science disciplines tend to experience the highest levels of mathematics anxiety (MASH, 2013). Participants belonged to four different faculties, with none from Arts and Humanities, potentially because mathematics plays a limited role in their assignments.

6.1.1.5. Degree level

Regarding degree level, 47.1% of participants were undergraduates, while 41.2% were postgraduate research (PGR) students, a significant overrepresentation compared to the university population, where only 9.1% are PGR students (Figure 15A). This skew may be due to the study's recruitment process, as PhD students were informed about the study well in advance and may have felt more inclined to participate due to their relationships with the researcher.

6.1.2. Mathematics anxiety scores

This section presents pre-game and post-game mathematics anxiety scores.

Thirteen participants completed both the pre-test and post-test mathematics anxiety scales. The average pre-game mathematics anxiety score was 69.3, which is notably high, considering that 76 indicates severe mathematics anxiety (Suinn & Whiston, 2003). After the play period, the average score decreased to 61.4, showing an overall reduction in mathematics anxiety. One participant's score was missing in the pre-game results, and when excluding this participant, the post-game average score remained consistent. A Wilcoxon signed-rank test was alos conducted.

6.1.3. Participant-Level Math Anxiety Changes

The researcher matched pre- and post-session data to compute each user's change in math-anxiety score (summing a 30-item anxiety scale at each session). Among the 13 participants with both pre- and post-data, 8 had decreased anxiety (post-score < pre-score), 4 had increased anxiety (post > pre), and 1 had no change (post = pre). In other words, after playing the game most users showed a reduction in math anxiety (8/13), while a smaller number showed an increase. The numerical change ranged from a 54-point decrease (largest drop) to a 12-point increase (largest rise) on the anxiety scale.

- Decreased anxiety (post < pre): 8 users
- No change: 1 user
- Increased anxiety (post > pre): 4 user

These counts are simple descriptive outcomes at the user level. A paired "before vs. after" plot (often called a *dumbbell chart*) can neatly display each user's pre- and post-score and highlight the direction of change.

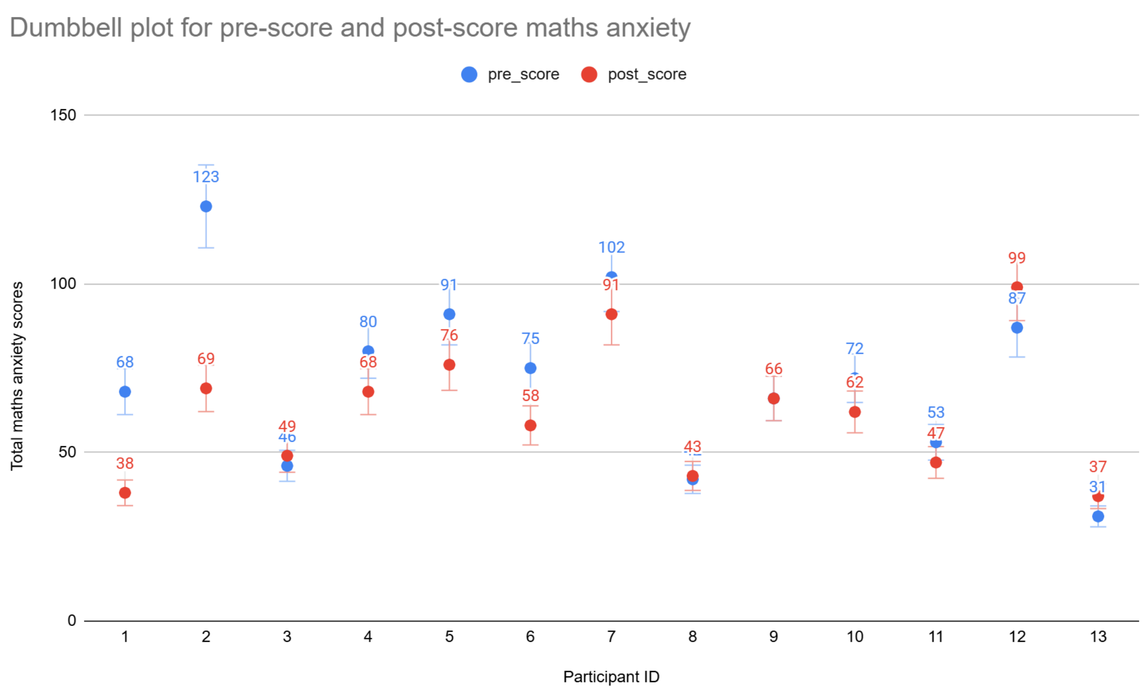

Figure 10: Dumbbell plot for pre-score and post-score maths anxiety

While a summary statistic (such as mean or median change) offers a concise overview, presenting individual difference scores alongside count data enhances transparency and highlights participant-level variability. This descriptive analysis complements, rather than replaces, subsequent inferential testing. Overall, the descriptive results show that the majority of users' self-reported math anxiety *decreased* after playing the game, with a few exceptions.

6.1.3.1. Justification for visual and individual-level analysis (Dumbbell Plot)

Individual-level visualisation was incorporated to illustrate participant-specific changes in mathematics anxiety. Such idiographic approaches are increasingly encouraged in educational psychology, as they reveal heterogeneity in intervention effects that group statistics can obscure (Dagnall et al., 2019; Bland & Altman, 1999). The dumbbell plot format allows direct comparison of each participant's pre- and post-intervention scores and has been recommended for representing paired data in behavioural studies. Including this analysis provides both transparency and richer interpretive depth regarding how individuals responded to the game.

6.1.3.2. Wilcoxon signed rank-test of pre- and post-game anxiety scores

Building on the findings visualised in the dumbbell plot, a Wilcoxon signed-rank test was conducted on the 13 matched participants who completed both pre- and post-session MARS scales.

The Wilcoxon signed-rank test produced $W = 14.0$, $p = .00497$, indicating a statistically significant median reduction in mathematics anxiety scores after gameplay.

This confirmed a significant reduction in mathematics anxiety following gameplay. The Wilcoxon signed-rank test was used instead of the Mann–Whitney U test because it accounts for the paired nature of the data, making it appropriate for comparing pre- and post-intervention scores within the same participants.

6.1.3.3. MARS-30 Brief subscale analysis

To gain a more detailed understanding of which aspects of mathematics anxiety were most influenced by gameplay, scores from the Mathematics Anxiety Rating Scale (MARS-30 Brief) were reanalysed using the six-factor model proposed by Pletzer et al. (2016). This model separates mathematics anxiety into six components:

- Evaluation Anxiety 1 (EA1) – anxiety when taking a mathematics test;
- Evaluation Anxiety 2 (EA2) – anxiety when anticipating a mathematics test;
- Learning Mathematics Anxiety (LMA) – anxiety when learning or studying mathematics;
- Everyday Numerical Anxiety (ENA) – anxiety in daily numerical situations (e.g., handling money, calculating bills);
- Performance Anxiety (PA) – anxiety when completing numerical operations or problem-solving tasks; and
- Social Responsibility Anxiety (SRA) – anxiety when others depend on one's mathematical performance.

Each participant's pre- and post-session scores were computed by summing the relevant items for each factor (see Appendix I for item mapping).

Paired-samples t-tests and non-parametric Wilcoxon signed-rank tests were used to assess within-subject changes (n = 13 matched cases).

Descriptive and inferential results

Table 6.3 presents mean pre- and post-intervention scores for each factor, together with *t*-statistics, significance levels, and Cohen's *d*.

Table 6.3 Pre- and post-game MARS-30 Brief subscale scores

Subscale	Pre Mean (SD)	Post Mean (SD)	Mean Δ (Post – Pre)	*t*(12)	*p*	*d*	Wilcoxon *p*
EA1 – Evaluation Anxiety (Taking Test)	16.31 (5.63)	13.31 (5.54)	–3.00	–2.87	.014 *	–0.80	.021 *
EA2 – Evaluation Anxiety (Anticipating Test)	15.46 (5.06)	13.92 (3.93)	–1.54	–1.76	.104	–0.49	.126
LMA – Learning Mathematics Anxiety	11.08 (4.11)	9.62 (3.78)	–1.46	–1.47	.166	–0.41	.187
ENA – Everyday Numerical Anxiety	9.08 (3.64)	8.31 (3.12)	–0.77	–0.84	.416	–0.23	.497
PA – Performance Anxiety (Arithmetic Tasks)	12.77 (6.87)	10.54 (4.59)	–2.23	–1.32	.210	–0.37	.198

SRA – Social Responsibility Anxiety	7.31 (3.35)	6.08 (2.40)	–1.23	–1.98	.071	–0.55	.050 †
Total MARS Score	72.00 (25.54)	61.77 (19.32)	–10.23	–2.14	.053	–0.59	.036 *

Interpretation

Significant reductions were observed for EA1, reflecting a moderate-to-large decrease in anxiety experienced while taking a mathematics test ($t(12) = –2.87$, $p = .014$, $d = –0.80$). The total MARS-30 Brief score also declined significantly at the .05 level in the Wilcoxon analysis ($p = .036$), confirming an overall reduction in self-reported mathematics anxiety following gameplay. The SRA subscale showed a medium effect size ($d = –.55$) and approached significance ($p = .071$), suggesting that participants felt somewhat less anxious when responsible for others' mathematical outcomes.

All other subscales (EA2, LMA, ENA, PA) exhibited reductions in the same direction, though these did not reach statistical significance. likely due to the small sample size. Nevertheless, the consistent pattern of decreases across all factors suggests that the intervention had a generally calming effect on participants' emotional responses to mathematical contexts.

Discussion of subscale patterns

The results indicate that the greatest improvement occurred in evaluation-related anxiety**,** particularly when taking a mathematics test. This finding aligns with prior evidence that evaluative situations elicit the highest physiological and cognitive interference in mathematics-anxious individuals (Ashcraft & Ridley, 2005) and with the factor-analytic work of Pletzer et al. (2016), who identified evaluation anxiety as the dominant dimension of the MARS-30 Brief.

The pattern observed here suggests that even a brief period of engaging with the educational game *Algebra Meltdown* reduced participants' fear responses associated with formal testing situations. In contrast, smaller reductions in learning- and performance-related anxiety imply that a single session may not be sufficient to alter deeper cognitive beliefs about mathematical ability or daily numerical confidence.

Collectively, these findings reinforce the conclusion that game-based interventions can effectively **lower situational test-related mathematics anxiety**, potentially improving learners' emotional readiness for assessment and encouraging greater persistence in mathematical tasks.

Overall, these results provide stronger evidence that the intervention's most immediate impact was on participants' test-related anxiety rather than their broader attitudes toward mathematics or numerical tasks. While the reductions in evaluation anxiety are encouraging, they may also reflect short-term emotional effects tied to the novelty and engagement of the gameplay session. To explore whether such reductions were influenced by the amount of time participants spent interacting with the game, the following section examines relationships between duration of playtime and mathematics anxiety outcomes.

The findings imply that even mini games can meaningfully reduce students' situational mathematics anxiety, especially in assessment-related contexts. This could have practical implications for university learning support and pre-assessment preparation. Incorporating brief, game-based warm-ups before exams or tutorials might help students regulate anxiety and approach mathematics with greater confidence.

However, the absence of significant change in learning- or everyday-related anxiety suggests that long-term anxiety reduction may require repeated exposure or blended interventions that address both cognitive beliefs ("I can't do maths") and emotional responses ("I feel anxious when calculating").

6.1.4. Duration of playtime

From the 155 diary entries, most participants (82%) played the game 1-3 times a day. PhD students were more likely to play regularly, which may be attributed to their personal connection with the researcher.

Not all participants played the game every day. Figure 18A below shows the number of diary entries each day of the study. The R squared line indicates a slight downward trend in daily play at .03, but no significant association between the number of participants playing the game and time of the study was found. This pattern also suggests that the study's timing during the academic holiday period may have influenced the level of engagement among undergraduates and taught postgraduate students, as many would have been balancing other commitments.

6.1.5. Daily anxiety levels

Over the play period, participants' mathematics anxiety was measured using a scale from 1 to 10. The average anxiety score was 2.59, with a 95% confidence interval indicating that mathematics anxiety levels remained low after playing the game (between 2.30 and 2.95). A further question on the diary study questionnaire asked participants to rate their general anxiety, also using a 1-10 scale.

A multiple regression was conducted to predict maths anxiety from the *Number of days playing the game* and *General Anxiety*. These variables statistically significantly predicted maths anxiety, $F(2, 14) = 14.16$, $p = .01$, adjusted $R^2 = .65$ indicates a high degree of maths anxiety is explained by the predictor variables.

The number of days playing the game contributed significantly to the model, $\beta = -.096$, $t(14) = -4.463$, $p < .00$, with a 95% confidence interval of [-.14, -.04]. This suggests that for each additional day spent playing the game, maths anxiety decreases by .096 units on average. In contrast, General Anxiety did not statistically significantly contribute to the prediction of maths anxiety, $\beta = .11$, $t(14) = 1.10$, $p = .29$, with a 95% confidence interval of [-.11, .33].

The overall model is statistically significant, confirming its predictive validity. However, diagnostics indicate some residual autocorrelation (Durbin-Watson = .74) and moderate multicollinearity (Condition Number = 58.7). These should be considered when interpreting the results.

In summary, the analysis suggests that the number of days playing the game is a significant predictor of decreasing maths anxiety over time, while General Anxiety does not show a significant association in this dataset.

6.2. Use cases

Three participants were selected for detailed case studies due to their extreme cases of mathematics anxiety scores, providing unique insights into the impact of the Bubble Function game. These participants represented significant outliers in terms of their anxiety levels and were chosen to illustrate the varied responses to the game.

6.2.1. Participant 20

This participant's mathematics anxiety score remained unchanged throughout the study, starting and ending at 66. Despite playing the game regularly, their anxiety levels did not fluctuate significantly. The stability in their score suggests that the game neither alleviated nor exacerbated their existing low levels of mathematics anxiety. This participant's consistent experience is presented in Table 5B. Their main concerns related to the game interface and progressing through higher levels rather than the mathematics content itself.

During the first day of playing, the diary showed participant 20 was confused about the best approach to doing calculations to maximise their score:

"Not understanding the scoring rules and thus whether I should do the calculations in my mind (to save time, but at the risk of making more mistakes) or using a pen and paper (potentially taking more time, but less likely to make mistakes)." (Participant 20)

Their heatmap showed minimal focus on the mathematical questions themselves, further emphasising that their anxiety was not heavily tied to the mathematical content but rather to game controls.

Figure 10: Participant 20 – Eye tracking heatmap

6.2.2. Participant 6

This participant began the study with extremely high mathematics anxiety, scoring 123 before playing the game. Over 30 days, their score nearly halved, dropping by 54 points to 69 by the end of the study. This drastic reduction indicates that the game profoundly reduced their anxiety, particularly about problem-solving tasks. Initially overwhelmed by the mathematical content, Participant 6 gradually developed confidence, which led to a sharp decline in their anxiety levels.

In the interview, when the participant was asked about graphics or the game being fun, the participant voluntarily emphasised that they were not confident with maths.

"To be fair when I did finish all the levels I did feel quite happy and quite proud of myself, but it's only because I considered myself really bad at maths. However I don't think many people will share the same feelings, because I do know people who are very good at maths would see this as completely childish, so to me personally it was. I couldn't say it was very euphoric moment, it's was just like "yeh, ok I've finished, well done." (Participant 6)

This participant's experience highlights the potential for game-based learning to significantly improve mathematical self-efficacy. As their mathematics anxiety decreased over time, the heatmap showed a gradual shift in focus towards the answers, indicating increased confidence in solving the problems.

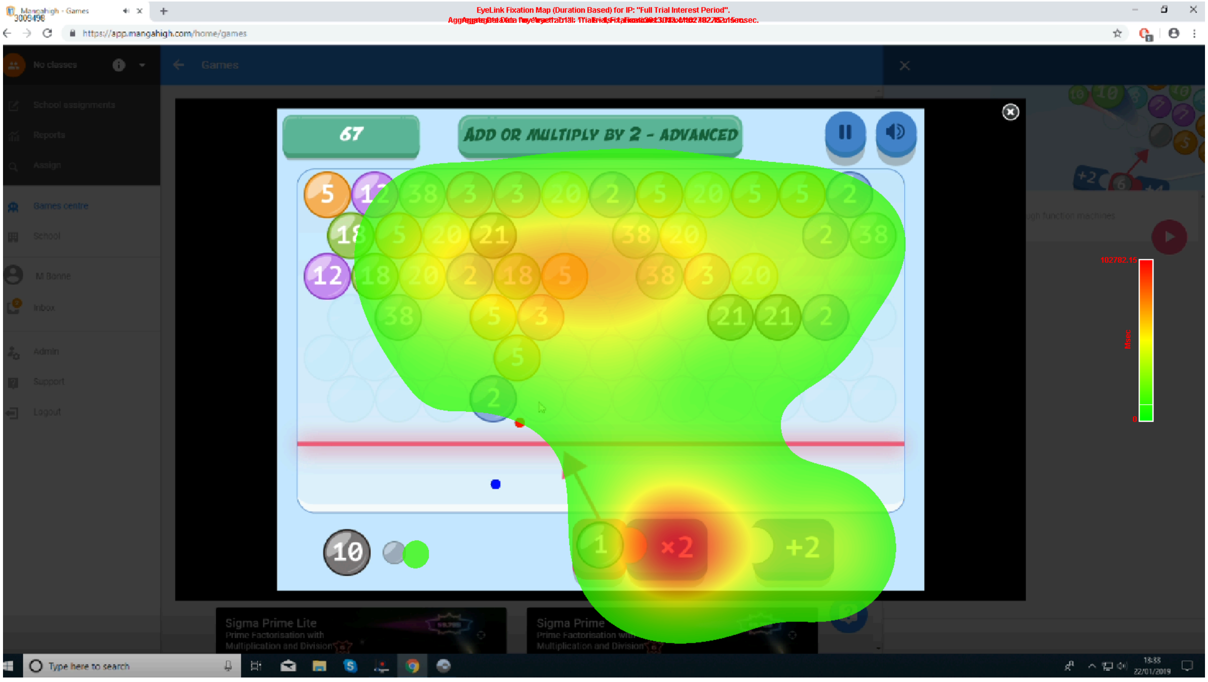

Figure 11: Participant 6 – Eye-tracking heatmap

6.2.3. Participant 2

One of the few participants to experience an increase in mathematics anxiety, Participant 2's score rose from 46 to 49 by the end of the study. Although the increase was modest, it is notable because this participant reported that the game's mathematical tasks were too simplistic compared to the more advanced mathematics they encountered in their research work. They found the game less engaging and expressed frustration with the unclear scoring system. Eye-tracking data revealed that Participant 2 spent a considerable amount of time switching between the sums and potential answers, particularly in the early stages of the study. This eye movement pattern indicates confusion with the game's interface, as the participant frequently mentioned in interviews their difficulty remembering to switch functions and their struggles with the game controls.

Participant 2 regularly referred to issues remembering to switch functions to get answer the right answer.

"Which I've mentioned many times, it's forgetting to switch functions. Which happened less and less and almost not at all later on. The bubble going where you don't want it go, these sort of UI... things more than "Am I able to multiply this by 10 to the power of -2."
(Participant 2)

This case illustrates that for individuals with advanced mathematical backgrounds, the game may not provide the appropriate level of challenge to reduce anxiety or foster engagement.

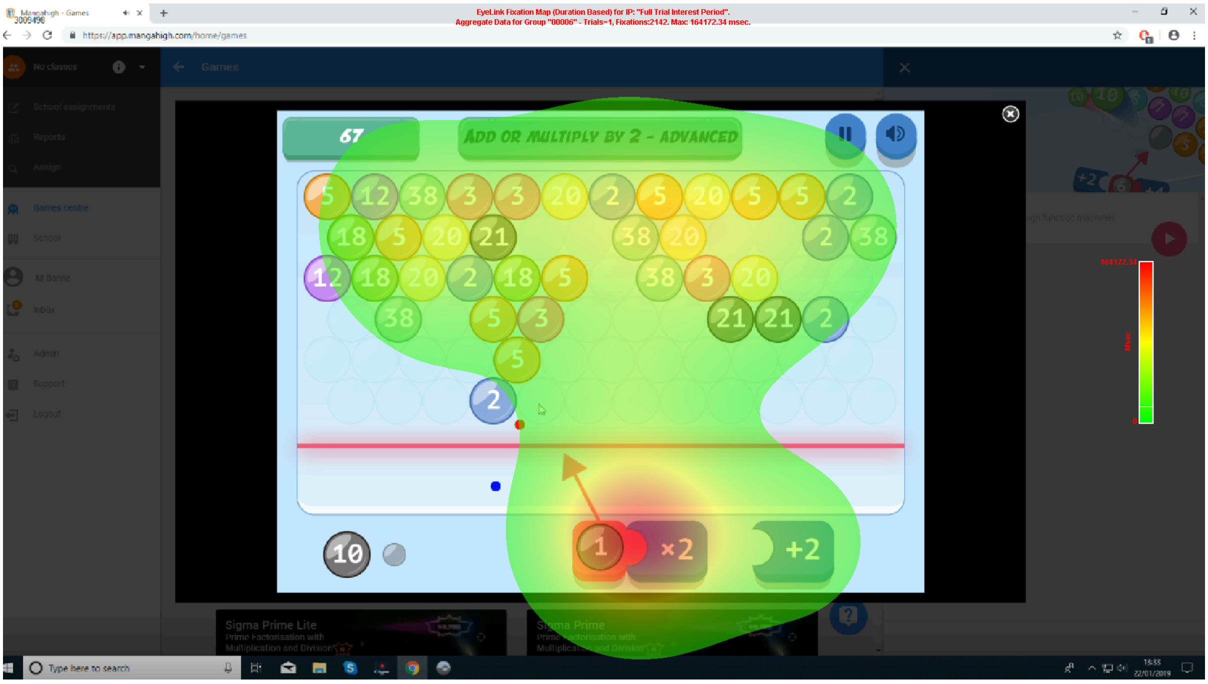

Figure 12: Participant 2 – Eye-tracking heatmap

6.3. Comparison of Mathematics Anxiety Rating Scales: MARS vs. Diary study 1-10 scale

6.3.1. 30-item MARS scale

The Mathematics Anxiety Rating Scale (MARS) contains multiple items that assess anxiety in various scenarios, such as solving maths problems, taking tests, or participating in class discussions. This comprehensive approach enables the MARS scale to capture various anxiety triggers related to different aspects of mathematical tasks. For example, a student may feel anxious about timed tests but not about classroom participation. By addressing these specific scenarios, MARS can provide a more nuanced and accurate understanding of a student's anxiety.

6.3.2. Diary study 1-item scale

In contrast, a custom 1-10 scale used in the diary study asks the single question, such as, "On a scale from 1 to 10, how anxious are you about mathematics after playing the game today?" This type of measurement is quicker and simpler, asking students to rate their overall anxiety level. It can be completed in seconds, making it a practical tool for situations where time is limited, such as classroom settings or daily evaluations of educational interventions. The brevity of the scale allows for more frequent assessments, helping educators track changes in anxiety over time without overwhelming students with a lengthy questionnaire (Dondio et al., 2023). Immediate feedback is particularly useful for monitoring the overall impact of interventions, such as an educational game, without delving into the specifics of what may be causing anxiety. The quick turnaround in data collection can assist in making timely adjustments to teaching methods or game design to better address students' needs (Bryant, 2023).

This format aggregates all aspects of anxiety into one overall score, which can lead to a generalised response. Since it does not differentiate between specific sources of anxiety, it may overlook important details about the causes or triggers of a student's anxiety. For example, after playing a game, a student might rate their anxiety as a "6" without distinguishing whether it arises from test anxiety or general discomfort with numbers. In contrast, the MARS allows researchers to determine whether the game specifically reduced anxiety in certain situations (e.g., computation tasks or word problems).

6.4. Eye-tracking metrics and cognitive load in Bubble Function gameplay

Analysis of the ocular metrics revealed substantial variability across participants. For example, blink counts ranged from about 88 to 639 blinks per session (mean ≈274), indicating wide differences in blink rate and potentially engagement or visual strain. Fixation counts also varied (roughly 1,450–3,800 fixations, mean ≈2,220), reflecting how often players' gaze paused. Mean fixation duration was about 266 ms (range ≈168–360 ms), falling within the expected 200–300 ms range for focused visual tasks (Mahanama et al., 2022). In general, longer fixations suggest deeper cognitive processing (Rayner, 1978; Salthouse & Ellis, 1980), so the higher end of our fixation durations implies that many participants were deeply concentrating on the math problems. Pupil size also showed a large spread (mean ≈810 in the device's units, range ≈421–1,303). Larger pupil diameters are known to index greater cognitive load or arousal (Hess & Polt, 1964; Kahneman & Beatty, 1966). Here, higher mean pupil sizes likely correspond to the greater mental effort involved in solving the game's problems. Finally, saccade amplitude (mean ≈4.9° visual angle, range ≈3.2–8.9°) tended to be on the small side. This is consistent with literature showing that saccades become shorter when task difficulty or cognitive load increases (Zelinsky & Sheinberg, 1997). In sum, the overall eye-movement patterns – long fixations, large pupils, and relatively small saccades – point to sustained attention and high cognitive processing during gameplay.

We also examined how these eye-tracking metrics related to participants' mathematics anxiety (MA) scores. Notably, those with the highest initial MA (e.g. a participant with a pre-score of 123) showed among the longest mean fixations (≈318 ms) and large pupil sizes (≈920), which could indicate that high anxiety was accompanied by greater cognitive effort on the math tasks (Blini et al., 2024). In contrast, participants with stable or low anxiety tended to have shorter fixations and smaller pupils (for instance, one participant with constant MA 70 had fixations ≈168 ms and pupil ≈556). These observations align with findings that high MA can prolong peak pupil dilation (reflecting sustained effort) (Blini et al., 2024). However, the correlations were not perfectly linear across all cases in this small sample. For example, some participants whose MA improved (scores dropped) did not always show obvious eye-metric differences, and vice versa. Overall, the data suggest a trend where greater MA (or greater change in MA) is associated with eye-movement indicators of higher cognitive load, but individual differences were large.

Interpretation of these results in the context of gameplay suggests that affective engagement and cognitive load were indeed reflected in the eye metrics. Longer fixations likely mean players were focusing intently on the bubble-operations, consistent with engaged problem-solving (Mahanama et al., 2022). Likewise, larger average pupil dilation indicates heightened mental effort; pupillometry is a well-established index of cognitive load, increasing with task difficulty (Kahneman & Beatty, 1966). Smaller saccades suggest participants scanned less widely and spent more time on specific elements, another sign of concentrated attention (since higher cognitive load often yields reduced saccade amplitude [Zelinsky & Sheinberg, 1997]). Blink behavior may also fit this picture: according to Siegle et al. (2008), blinks tend to occur after sustained processing, whereas pupil dilation reflects the active processing itself. In our data, participants generally blinked at moderate rates, implying most time spent in sustained computation rather than frequent breaks in focus.

In summary, the eye-tracking metrics point to substantial cognitive load during the Bubble Function game, particularly among those with higher math anxiety. Mean fixation durations were on the high end of normal (~200–300 ms; Rayner, 1978; Salthouse & Ellis, 1980), and pupil sizes were elevated for some individuals, both indicators of deep processing. These patterns support the idea that gameplay elicited serious mental effort. Importantly, participants who were more math-anxious showed metrics (longer fixations, delayed pupillary peaks) consistent with exerting extra effort or experiencing stress during math tasks (Blini et al., 2024). These findings reinforce existing theory that eye-tracking measures (fixations, pupil dilation, saccades) can serve as objective proxies for cognitive load and emotional arousal in educational settings (Mahanama et al., 2022; Siegle et al., 2008).

6.5. Study 4 summary

Overall, Study 4 found that playing educational games, such as Bubble Function, reduced mathematics anxiety for participants, particularly those with initially high levels of anxiety. The gender and nationality of participants influenced their anxiety levels, with females and certain nationalities experiencing higher mathematics anxiety. Eye-tracking data supported these findings, showing that participants with higher anxiety spent more time focusing on mathematics problems rather than potential answers.

7. Discussion

7.1. Research objectives

7.1.1. To investigate the impact of games on mathematics anxiety in University of Sheffield students.

One of the objectives of the research was to investigate the use of educational games in addressing mathematics anxiety in University students. Overall the game reduced mathematics anxiety among the sample population with the highest reduction coming from high mathematics anxiety students. This agrees with the previous studies researching browser-based games, such as Jansen et.al (2013) whose experiment involved 252 children 8-13 year olds. Furthermore, Jansen et.al's (2013) study found that the experience of success within the games also reduced their mathematics anxiety, this was a recurring theme from the interviews in this research, where participants felt that completing harder difficulty levels boosted their confidence. Ultimately, the use case results show students of varying mathematics anxiety levels react to the game differently. Those with low mathematics anxiety reported to find the game boring with the same type of maths problems re-occurring for each session, perhaps more significantly low mathematics anxiety stated they would not play the game in their free time other than games. Those with high mathematics anxiety were more engaged with the maths problems throughout the study, with some participants even stating they would play the game casually to practice their maths skills.

7.1.2. Review the literature to identify mathematics anxiety scales and computer games that could potentially be used for data collection

The literature was reviewed identifying the several scales that could be used for the study. It should be noted that since data collection, more mathematics anxiety scales may have been created that could have been more appropriate for the study and its participants. For example, this research methodology evolved to collect data on student confidence in maths (more commonly referred to as self-efficacy in the mathematics anxiety literature). Upon researching the literature it was found Gabriel et al (2019) had used the Mathematics Self-Efficacy and Anxiety Questionnaire (MSEAQ) for their data collection, this particular questionnaire was developed by May (2009) and aimed at college age students, and could be used in future mathematics anxiety studies that aim to collect similar data.

Furthermore, there was an investigation into which games to use for the study. With no particular standard in the games used in mathematics anxiety literature. Ultimately there were little to no browser-based maths games aimed at university students or adults in general. Only a few were identified for Study 1 that were geared towards adults, but were largely rejected by participants for being too simple and repetitive. Only one game (Algebra Meltdown) did participants state that they would play again in their own time, however the game was taken down by the developers due to a lack of player-base and replaced with Bubble Function. It should be noted that Bubble Function was also redesigned post data collection with new theme, sound and graphics. While unclear why, the development company mentioned the game was one of their most popular ones. Future studies may want to look into using the updated version of the game for any mathematics anxiety studies involving university students and compare its effectiveness with the iteration used in this study.

7.1.3. Mathematics activity in the everyday lives of University of Sheffield students.

This study also investigated mathematics activity in the everyday lives of University of Sheffield. Shopping and management personal finance were the most common scenarios among the sample of 125 students. This contrasted with Study 4, which involved a much smaller sample of 17, with participants mostly postgraduate taught and research students, rather than undergraduates. 23% of the activities involved calculating the time, and 17% involved handling money, 12% involved cooking, and surprisingly few went shopping at 1.5%, which was a majority activity for the Study 2 questionnaire. Where correlation occurred was then categorising those activities with Bishop's (1998) everyday mathematics framework. Similar to the everyday mathematics questionnaire, the majority of activities involved counting and measuring. When asked about the stories in the game during the interviews, participants felt that the game could involve a higher purpose other than clearing bubbles from the screen. One participant voluntarily brought up examples of "helping someone do their homework" or "saving the princess".

The most frequently occurring mathematics topic was arithmetic. It could be assumed that had the study included the student jobs and university courses as part of the everyday activities, the results may have been different. It may have become harder to find trends in specific activities due to the variety of jobs that students do. That said, when researching the literature on jobs that students adopt throughout their degree, arithmetic is still the most occurring mathematics topic (Swain, 2007).

An additional finding is that dieting did not occur as a particular activity, despite 19% of students known to employ “favourable eating behaviours” on a daily basis (Tanton, Dodd, Woodfield, & Mabhala, 2015), however a few participants from the University of Sheffield were known to check the nutrition on food packaging in terms of weight and calories before eating.

A small minority of students were known to play handheld computer games such as Fire Emblem and Pokemon which were stated to incorporate arithmetic and algebra. In search of suitable games for use that may impact mathematics anxiety these games may be worth including in future studies.

Future studies may want to directly ask participants what storylines they would suggest for a game either in questionnaire or interview form.

7.1.3.1. Agreement with existing frameworks

The categories identified in this study align closely with existing literature on everyday mathematics. Carraher and Schliemann (2002), for instance, reviewed studies on children and adults across multiple countries and found that buying and selling were the most common mathematical activities. Their study also highlighted arithmetic, measurement (e.g., time, weight, length), geometry, and probability as key topics. Similarly, university students in this study predominantly engaged with arithmetic, reflecting Carraher and Schliemann’s findings. Additional topics identified included statistics, fractions, estimation, unit conversion, and calculating time—though the latter was notably the least common activity, a pattern also observed in Carraher and Schliemann’s research.

Bishop (1988) proposed six high-level mathematical themes observed across different cultural groups: counting, locating, measuring, designing, playing, and explaining. Many of the activities in this study fit within these themes. However, an additional category, "Predicting," emerged, encompassing activities such as estimating length, width, and height, as well as cost approximations (see Fig. 24). While Bishop’s study did not quantify the frequency of mathematical activities, it examined a broader range of mathematics topics than this University of Sheffield study, likely due to its inclusion of workplace and academic contexts within everyday mathematics. Nevertheless, the emergence of Predicting suggests an evolving mathematical category that may not have been explicitly captured in Bishop's study. An updated version of his research could potentially reveal similar findings.

As illustrated in Table 13 and Figure 13, counting, measuring, and predicting were among the most frequently occurring mathematical activities. These findings reinforce existing frameworks while highlighting variations in how mathematical concepts are recognised and applied in daily life. While arithmetic remains dominant, areas such as time measurement occur less frequently, raising questions about their practical relevance and use in everyday activities.

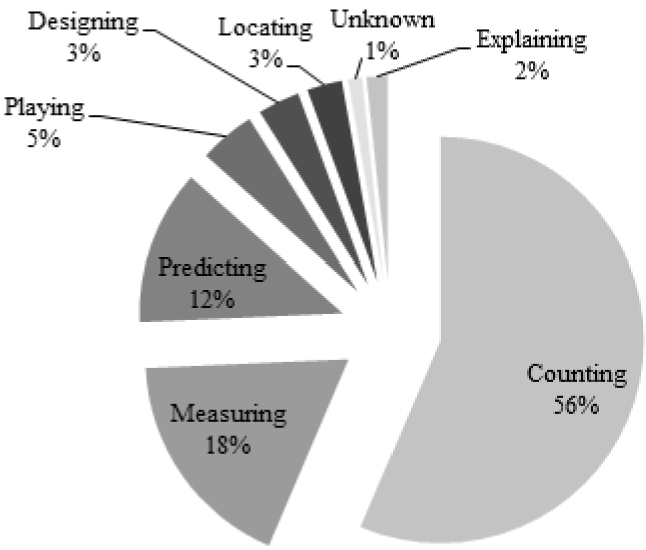

Figure 13: Everyday mathematics experienced by university students

7.1.3.2. Predicting category

The Predicting category is based on its definition from the OED, (2017). To predict means:

"To state or estimate, esp. on the basis of knowledge or reasoning, that (an action, event, etc.) will happen in the future or will be a consequence of something; to forecast, foretell, prophesy…".

While Bishop (1988) places "Predicting" as a sub-category of "Explaining", much of the statistics literature address the various differences between the predicting and explaining constructs (Dowe et al., 2007; Hitchcock & Sober, 2004; Shmueli, 2010) placing them into separate categories.

Based on the activities identified in the dataset, the type of mathematics involved in predicting would appear to consist of financial arithmetic, statistics and probability (percentages and fractions), time estimations, speed/distance/time estimations, length/width/height estimations, cost approximations, general rounding. The adaption of Bishops (1998) framework leads to the following model on Table 13.

Table 13: Adapted model of Bishops (1988) framework of everyday mathematics

Categories	Example activities from current analysis	Mathematics topics
Counting The use of a systematic way to compare and order discrete phenomena. It may involve tallying, or using objects or string to record, or special number words or name	· Shopping (counting cash) · Splitting the bill – restaurant (arithmetic) · Creating an exam revision timetable (Adding and counting days)	Numbers. Number patterns. Number relationships. Developments of number systems. Algebraic representation. Infinitely large and small. Events, probabilities, frequencies. Numerical methods. Iteration. Combinatorics. Limits
Locating Exploring one's spatial environment and conceptualising and symbolising that environment, with models, diagrams, drawings, words or other means	· Creating a map for a computer game (trigonometry, coordinate system calculations, angle and distance conversions). · Driving long distances (calculus)	Position. Orientation. Development of coordinates - rectangular, polar, spherical. Latitude/longitude. Bearings. Angles. Lines. Networks. Journey. Change of position. Loci (circle, ellipse, polygon ....). Change of orientation. Rotation. Reflection
Measuring Quantifying qualities for the purposes of comparison and ordering, using objects or tokens as measuring devices with associated units or 'measure-words'	· Calculating time difference between two countries before a video chat (time calculations) · Calculating time needed to complete different parts of an exam (time calculations, arithmetic) · Measuring time spent working out (time calculations)	Comparing. Ordering. Length. Area. Volume. Time. Temperature. Weight. Development of units - conventional, standard, metric system. Measuring instruments. Estimation. Approximation. Error
Designing Creating a shape or design for an object or for any part of one's spatial environment. It may involve making the object, as a 'mental template', or symbolising it in some conventionalised way.	· Coding a map for a computer game (trigonometry, coordinate system calculations, angle and distance conversions). · Programming personal project (games) · Knitting (multiplying stitch numbers to resize patterns)	Properties of objects. Shape. Pattern. Design. Geometric shapes (figures and solids). Properties of shapes. Similarity. Congruence. Ratios (internal and external)

Categories	Example activities from current analysis	Mathematics topics
Playing Devising, and engaging in, games and pastimes, with more or less formalised rules that all players must abide by	· Playing tabletop game Pathfinder (arithmetic) · Playing computer game Hearthstone (addition) · Playing poker (probability)	Puzzles. Paradoxes. Models. Games. Rules. Procedures. Strategies. Prediction. Guessing. Chance. Hypothetical reasoning. Games analysis
Explaining Finding ways to account for the existence of phenomena, be they religious, animistic or scientific	· Mock experiment measuring the effects of nostalgia on maths abilities (Subtraction from numbers with decimals) · Helping kids revise for exams (multiplication, long division, fractions, percentages) · Statistics exam (explaining outcomes using probability	Classifications. Conventions. Generalisations. Linguistic explanations - arguments, logical connections, proof. Symbolic explanations - equations, formulae, algorithms, functions. Figural explanations - diagrams, graphs, charts, matrices. (Mathematical structure - axioms, theorems, analysis, consistency.) (Mathematical model - assumptions, analogies, generalisability, prediction.
Predicting To state or estimate, esp. based on knowledge or reasoning, that (an action, event, etc.) will happen in the future or will be a consequence of something; to forecast, foretell, prophesy.	· Budgeting · Gambling · Planning events/gatherings. · Estimating physical size (e.g. wrapping boxes) · Estimating distance or petrol required (travelling). · Estimating price for purchases.	Financial arithmetic, statistics and probability (percentages and fractions), time estimations, speed/distance/time estimations, length/width/height estimations, cost approximations, rounding

7.1.3.3. Transfer

One concern was that the psychological benefits of the game may not necessarily transfer to alternative environments. In a way, this correlates with existing everyday maths literature such as Carraher (2002), who found a reduced ability of students to solve the same maths problems in school compared to out of school contexts. In Carraher's research, students were more confident with the use of physical objects such as money in a shop, rather than pen and pencil computation in the classroom. In this research however, added time pressure, and being watched by customers made participants less able to perform in their work environment, compared to solving maths problems at home, solitarily using the game. One suggestion for educators and trainers would be to design games that closely resemble or even simulate the environment where the mathematics activity is taking place. The familiarity should reduce anxiety when the student is exposed to maths in real life. Numerous studies have recommended similar design approaces, emphasizing close to real life simulations to maximise transfer (Kirkam, 2013; Alexander et. al, 2015; Aebersold, 2018). One particular concern in the findings for this research was some student's preference for more cartoony graphics and characters in their games, which goes against more human true-to-life graphics advocated in the papers. In this case, designers may wish to combine scenarios involving mathematics with less real-world graphics, however further research would be needed to test their effectiveness in reducing mathematics anxiety.

7.1.3.3.1. Unexpected preference for cartoon graphics

Participants in our study showed a clear preference for cartoon-style graphics over realistic graphics, an outcome that contradicts much of the existing literature on visual preferences. Typically, users are thought to favor realistic, high-fidelity visuals for their authenticity and immersion. For example, Selmbacherová et al. (2014) found that high school students overwhelmingly preferred a photorealistic version of an educational history game, rating it more *authentic* and *attractive* than a cartoon version. Similarly, in a serious gaming experiment, about 69% of participants chose photorealistic avatars over animated ones (vs. only 25% preferring the cartoon style). Several factors could explain why our University of Sheffield sample diverged from this pattern. One explanation relates to participant demographics and experience: as young adult university students, they likely grew up with stylized graphics in popular games and media, making cartoon aesthetics feel familiar and engaging. Many of our participants may not have been hardcore "graphics-first" gamers, so they were drawn more to the fun, approachable vibe of the cartoon style than to the promise of realism. Another factor is that the cartoon design may have simply better suited the context of an educational game. Stylized visuals can avoid uncanny valley issues and reduce extraneous detail, thereby lowering cognitive load (Skulmowski, 2022) and keeping players focused on gameplay and learning. The cartoon graphics likely signaled a playful, low-pressure environment, which aligns with students' expectations for a game-based learning experience. Indeed, prior work noted that animated characters can *"make the task feel more like a game"*, potentially boosting engagement. In contrast, unless executed at very high fidelity, the realistic graphics might have felt less polished or even distracting to these students. Thus, the preference for cartoon visuals in our study likely stems from a combination of our participants' generational aesthetic preferences, their gaming familiarity, and the cartoon style's alignment with a fun learning context (as well as avoidance of the pitfalls that can accompany lower-end realism).

7.1.3.3.2. Graphics preferences - implications for theory and practice

Theoretically, this finding challenges the assumption that higher realism is inherently more engaging, suggesting that models of user engagement and multimedia learning should account for audience context and preferences rather than treating realism as a universal good. Practically, it indicates that educational game designers should not default to photorealism for university students, stylized, cartoon graphics can be a viable and even preferable alternative, potentially enhancing learner engagement while also being resource-friendly for developers.

7.1.3.4. Significance of findings

The results are important for two reasons. It is now understood the kind of activities involving mathematics that students are exposed to daily, which may seem routine to them. In realising relatable real-world activities involving mathematics there is now a list of scenarios to incorporate into a game. Furthermore, in the absence of computer games, teachers could incorporate simulations, roleplays or simply provide examples of these activities in their classes as a way of demonstrating real world application for abstract mathematics topics.

The second implication is that despite such a specific demographic of students (i.e. University of Sheffield students), Study 2 results are similar to results of studies undertaken with other populations. It could be that incorporating similar activities into games may be effective in reducing mathematics anxiety and improving learning for a wider audience.

7.2. Developing a model to identify attributes of a game that impact mathematics anxiety

This section discusses the game attributes that impact mathematics anxiety (Research Objective 4) and uses them to develop a model which identifies attributes of a game that impact mathematics anxiety" (the main aim of this research).

When compared with Study 1 the game attributes that caused mathematics anxiety were largely the same despite a different game being used (Algebra Meltdown). This indicates a standard set of attributes that game designers should watch for when developing educational maths games. Figure 14. overleaf shows the model.

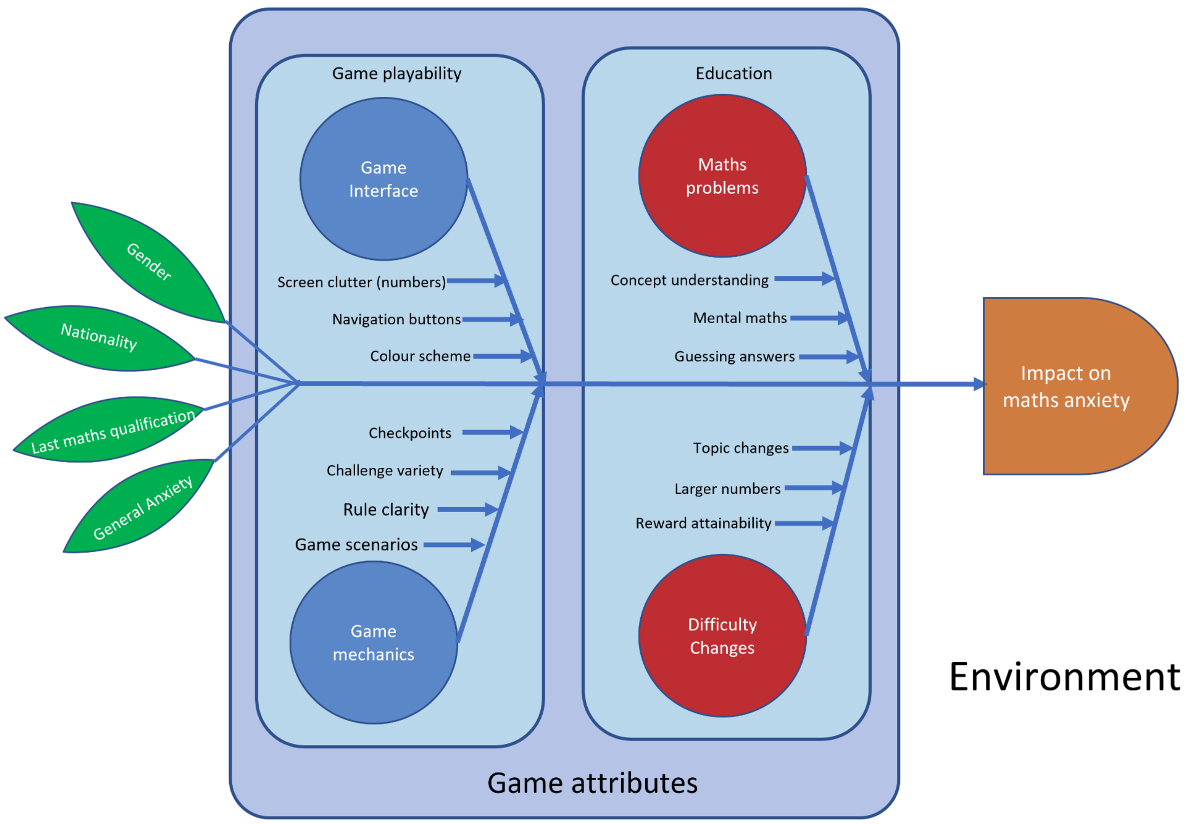

Figure 14: Cause and effect diagram: Game attributes that impact mathematics activity

Throughout Study 1 and 3 the researcher identified several game related causes that affected almost every participant to various degrees depending on their mathematics anxiety levels and previous gaming experience.

The game related causes were split into Game Playability and Education dimensions.

Game playability as defined by Desurvire et al. (2004) refers to multiple elements of a game which have been identified in the diagram, in particular, game mechanics and game usability (which includes game user interface).

The Education dimension covers the educational aspects of the game. The Oxford dictionary defines education as "The systematic instruction, teaching, or training in various academic and non-academic subjects given to or received by a child, typically at a school; the course of scholastic instruction a person receives in his or her lifetime. Also: instruction or training given to or received by an adult" (Oxford, 2019).

7.2.1. Environment dimension

The environmental dimension of a fishbone model refers to the physical, social, and economic factors that can affect a particular problem (Hassan & Alam, 2018). This dimension includes a range of factors, such as natural resources, climate patterns, land use, and economic policies, that can influence the problem being analyzed. The inclusion of the environmental dimension in a fishbone model can provide a more comprehensive understanding of the root causes of a problem and help develop effective strategies for addressing it.

7.2.2. Educational dimension

7.2.2.1. Maths problems

Solving more complex mathematical problems in the game was the primary source of anxiety for participants with high levels of mathematics anxiety. The diary study revealed that participants with moderately high mathematics anxiety (scores of 80–90) gradually gained confidence through practice, especially as they began solving problems correctly. However, for those with severe mathematics anxiety (scores of 100–120), complex problems remained a persistent source of stress throughout the study.

Concept Understanding

For this dimension, a participant in Study 4 described not fully understanding mathematics concepts presented in the game. One way to address this would be to have optional learning instructions (presented as text) on each level when the game is paused, which has been shown to improve deep learning (Erhel & Jamet, 2013).

Mental Maths

Participants with higher than normal mathematics anxiety found it harder to think when coming across more advanced maths problems (e.g. exponentials, standard forms), impeding their ability to mentally process the numbers, and beginning a vicious cycle of getting wrong answers and increasing their mathematics anxiety.

> “I think so, apart from when you get to the higher levels, and they expect you to know what the concepts mean straight away. I was definitely having to work backwards and figure them out, which was interesting in itself and little bit intimidating”. Participant 6

This indicates a weak short-term memory, and as the issue stems from not seeing the workings written down, one way to reduce mathematics anxiety in this case would be to have optional in-game pointers and suggestions indicating how to solve certain problems (Rushworth, 2013: Lee et al, 2013) then switching said pointers when they feel comfortable.

Guessing answers

In relation to the factor of Concept Understanding, participants struggling to process a maths problem would resort to guessing answers.

“Not understanding the concepts and thus whether I should guess to save time, but at the risk of making more mistakes, or using a pen and paper, potentially taking more time, but less likely to make mistakes (Participant 00002).

The lack of true understanding and recurring maths avoidance would sustain their mathematics anxiety levels the next time the same problem occurred in the game. One way to reduce mathematics anxiety and promote deeper thinking would be to use the Confidence Assessment approach (or CA approach). This involves an extra box in the game allowing the player to input how confident they are (rating of 1, 2, 3) with their answer. If the participants' answer is correct, the number of points they receive is the same as their selected confidence level. Conversely if their response is incorrect, the player receives a penalty of 0, 2, 6 points. This rewards participants who behave rationally and state their true confidence more generously and penalises those who underreport or overreport their confidence more severely. The CA approach has proven to be particularly effective for university students who tend to overestimate their performance. When implemented, CA encourages students to self-check and self-explain, often adjusting their answers in response to a request for the CA score (Foster, 2016).

7.2.2.2. Difficulty Changes

This affected all but the lowest mathematics anxiety participants. Difficulty changes refers to unexpected spikes in difficulty in the maths problems in the game. The highest mathematics anxiety participants stated that the game went from basic addition to powers with no explanation of the operators to be used beforehand. From study 1 and 4, three dimensions to Difficulty Changes were identified.

Topic changes

Participants were often concerned about sudden changes of topic, which they felt they were not ready for due to a steep learning curve and lack of guidance or instructions from the game. For example, in Study 4, participant 6 stated concern about how the game went from addition and subtraction to squaring and cubing whereas multiplication and division seemed more like a progressive topic change. Another approach to boost self-efficacy and increase engagement would be automated difficulty scaling, where the game keeps a record of the players progress and switches to easier topics when the participant begins to struggle (Spronck, 2014).

Larger numbers

Participants with high mathematics anxiety experienced particular difficulty dealing with a sudden change from small numbers to larger or awkward numbers. Larger numbers took longer to solve and participants noticed more errors occurring. This is a common issue in mathematics anxiety literature due to the increase in working memory required to manipulate longer range of digits (Prado, 2013). It is suggested that participants are gradually exposed to larger numbers in the game as students with high mathematics anxiety tend to have not frequently encountered large numbers in schools and may not have to deal with them on a daily basis (Pinheiro et al, 2017).

Reward attainability

Medium to high mathematics anxiety participants voiced concerns that to achieve the same reward (e.g. 3 stars) in higher levels of the game required much more effort than levels containing easier maths problems. While this reward style may seem logical at first glance, the literature on game designs show computer games become more immersive when the player is more generously rewarded for completing higher levels of the game (O'Donovan, 2013).

7.2.2.3. Game mechanics structure

Game structure refers to the rules and boundaries of the game. For example, the Bubble Function game participants can shoot balls directly at a wall and have them ricochet to reach their target. The levels of themselves are linear, set in one environment with no room for exploration. Furthermore, participants simply had to get from the beginning to the end of the game, there were no checkpoints, though they could choose to replay a level they had completed before adding an extra layer of structure to the game. Three issues arose in relation to the structure that participants felt increased their mathematics anxiety.

Checkpoints

Checkpoints are areas or stages of the game that can be saved and played again later, rather than having to start a game all over again. Bubble Function did not have this feature, and high mathematics anxiety participants voiced their concerns about playing the game from the beginning after the mental effort and time required to reach the very last level, which they felt invoked their mathematics anxiety further. An effective way to use checkpoints would be to place them at the end of each level, or have players earn checkpoints as a bonus by completing certain tasks (Hitchens, 2006).

Challenge variety

This dimension looks at the diversity of the encounters in the game. In this case, participants referred to the type of maths problems as well as game mechanics of shooting answer bubbles to matching bubbles. The lowest and highest mathematics anxiety participants in Study 4 felt the game needed a wider range of tasks to maintain replayability. Participants with medium to high levels of anxiety, or those with an average decrease in mathematics anxiety felt the array of challenges were adequate and would play the game again for more confidence. For the lowest mathematics anxiety participants, it was repeatedly stated that the maths challenges were boring and too easy, whereas the highest mathematics anxiety participants were expecting more story and a wider variety of encounters but struggled with maths concepts. It may be possible to cater to both groups by adding additional challenging maths encounters towards the end of the game for low mathematics anxiety participants who simply want to sharpen their maths skills. For high mathematics anxiety participants, providing some background story that are both relatable (similar to Study 2 scenarios), encompasses the maths concepts being taught, for example basic addition and subtraction could be linked to scenarios about shopping or working in a shop. Other studies have found these types of stories increase engagement, particularly with subjects in the STEM fields (Gee et.al., 2017).

Rule clarity

Rule clarity refers to the participant understanding the objectives and boundaries of the game. This was a particular concern by low mathematics anxiety participants, who felt their mathematics anxiety increased, not being sure how the game calculated their scores and what extra actions they needed to take in the game to boost the numbers. Perhaps not surprisingly, high mathematics anxiety participants were not too concerned about how the score system worked as long they passed to the next level. One way around this, would be to provide more detailed feedback at end of each level on where students went wrong in the game, and what they need to either in terms of maths problems or game mechanics to improve their score, such feedback is particularly important in reducing mathematics anxiety (Nunez et.al., 2015).

Game scenarios

In the Study 2 data, a number of typical activities were found that students regularly engage in and involve mathematical concepts. These activities consist of managing personal finances, planning events, cooking, and shopping, which can be found in section 5.2.2. Educational games can be developed with one or more of these activities as scenarios, akin to the Giving Change game used in this study. Students would be more comfortable in real-life situations related to math since they are already familiar with these relatable environments and tasks. Study 1 interview data showed that the game scenarios had a positive impact on participants' anxiety levels, with the shopping mental math game being the most preferred scenario due to its relatability (read section 5.1.2.3).

7.2.2.4. Game user interface

This is essentially the graphics and layout of components on screen. In the diary entries in Study 4, participants were particularly concerned about colour scheme, the positioning of balls, the direction they travelled in as well as how many balls were on screen at once. These factors all seemed to have some impact on mathematics anxiety. There were also several concerns about the sound, namely the repetitive music, with low mathematics anxiety participants often preferring to play their own music over the original sound. While still a factor, this was not included in the diagram as there were so few occurrences of the theme. Otherwise there were main game interface elated affecting mathematics anxiety as discussed below:

Screen clutter

Screen clutter refers to the number of items on screen appearing at once, such as the balls in Study 4. This was a particular concern for high mathematics anxiety students, as wrong answers led to more balls appearing on screen they were required to clear. The only way to clear them was by getting the correct answers. Even though the game had no timer, seeing the increasing numbers of balls on screen provided the illusion that they had to start getting the correct answer before their screen would be filled with balls and they would lose the game, increasing the sense of urgency, and their anxiety about maths. As seen from the eye-tracking heat maps, high mathematics anxiety participants spent most of their time focusing on the getting the right answer from sums at the bottom of the screen, and little time on the balls containing potential answers appearing near as this confused participants, adding more to the cognitive load, and leading to participants guessing answers. Previous studies have identified performance drops in tasks where there are too many objects on screen at once, and recommended briefly highlighting the most important content (e.g. the answers) that the player can focus on to reduce the spread of attention (Moacdieh, 2015; Marsh 2015).

Navigation buttons

A particular issue for low mathematics anxiety participants in Study 4 was forgetting to switch functions when needed so the number cannon could shoot the correct ball at potential answers. As demonstrated in the eye-tracking participants, low mathematics anxiety participants would, early on in the study, spend less time looking at the function switch at the bottom of the screen, assuming that they had worked out the answers in their heads that all they had to do was fire the cannon with the right answer. After getting the wrong answer, this would lead to frustration and raise their mathematics anxiety. Other studies recommend regularly highlighting any controls or buttons that are essential to the player's progress (Piotrowski, 2009).

Colour Scheme

Colour scheme mainly refers to the colours of items on the screen: in Study 4 this referred to the balls. For high mathematics anxiety participants, the colours of balls came up frequently perhaps as they believed each attached some meaning. Occurrences of the "black ball" or "grey ball" which technically bore no relation to players performance, indicated some degree of failure, increasing mathematics anxiety. That said, participants complemented that the game used different colours for potential answers on screen, as having them all as the same colour would have created a "wall of text" effect, making them take longer to find potential answers. Participants also referred to the "red line". This is a line lowering down the screen: if it touched the bottom it indicated that participants had got too many wrong answers and would have to start again. Other studies recommend properly considering how different colour schemes might be related to thoughts and feelings of the player and adjust them to control the player's behaviour (Helin, 2006).

7.2.3. Non-game related factors

While there are factors resulting from playing the game that may impact on mathematics anxiety, game developers may wish to consider external factors that may affect the players experience with the game, and in turn affect their mathematics anxiety levels.

7.2.3.1. Environment

From the diary study and the interviews in Study 4, it becomes apparent that different environments have varying impact on mathematics anxiety. During the interviews, participants with high mathematics anxiety referred to the room as a possible source of anxiety, where the study was taking place. In the iLab (where observations of gameplay were conducted), this consisted of 4 wall cameras, a one-way window so the researcher could view the participants' environment while they play the game, and also windows with the blinds shut to avoid the eye tracker, picking up too much light from the outside. Participants referred to the décor of the room as rather clinical and felt they were being "watched" on their performance, which provoked their anxiety.

Other participants referred to their work as a possible source of anxiety, e.g. (in Study 1) working in a shop having to count change for customers as they waited in a queue. During the diary study, participants did not refer to a specific environment as a possible source of anxiety, but stated that they felt anxious being "watched", were under time pressure and that were at risk of criticism by other people, which agrees with much of the literature (Goodman, 2018; Rohman, 2019). Furthermore, when high mathematics anxiety participants were asked if they would welcome the idea of a leaderboard so players could compete on scores as a possible motivator, participants stated the functionality would make their anxiety worse.

From the findings, it can be seen that for high mathematics anxiety university students, allowing the game to be played privately, single player, and in their own chosen environment could be an effective way to reduce anxiety and build confidence in maths. This is one difference compared to school students, who in the literature claim to prefer multiplayer maths games (Ahmed, 2018). If multiplayer is a necessary requirement the game should be played cooperatively rather than competitively (Fengheng & Grabowski, 2007).

7.2.3.2. Gender

Similar to earlier studies on mathematics anxiety of all age groups, there was a slight difference in mathematics anxiety among males and females, with females having slightly higher mathematics anxiety than males (Dowker et al., 2016).

This is consistent with other studies measuring mathematics anxiety between genders. Pourmoslemi, Erfani, and Firoozfar (2013) found that female undergraduate students experienced greater anxiety, potentially influenced by societal stereotypes regarding gender roles in mathematics. Similarly, Morán-Soto and González-Peña (2022) identified a pronounced gender gap in Mexican engineering students, with females reporting more anxiety, particularly at the college level. Baloglu and Kocak (2006) also revealed that females faced higher anxiety when engaging in mathematical tasks, suggesting that societal expectations and early education experiences contribute to these disparities. Stoet et al. (2016) further confirmed this trend across cultures, observing that the gender gap in mathematics anxiety widened in countries with greater gender equality, suggesting that cultural attitudes play a crucial role. Goetz et al. (2013) proposed that the higher anxiety reported by females may stem from social expectations and self-perception, despite comparable mathematical performance to males. Collectively, these studies underscore the need for interventions to reduce mathematics anxiety among females and challenge entrenched societal stereotypes.

For future research, it is recommended to explore the factors of the fishbone model of game attributes that may influence mathematics anxiety in females, with particular attention to elements such as storyline, character development, and emotional engagement. Testing these attributes individually or in combination could provide insights into how different game features affect the levels of anxiety in female students.

Additionally, it may be valuable to conduct a separate study focusing on males to determine whether the same factors influence their mathematics anxiety in similar or different ways. This gender-specific approach would allow for a more nuanced understanding of how game attributes impact anxiety in males versus females and could help design more effective interventions tailored to each group.

By examining these factors in controlled, gender-based studies, researchers can better understand the relationship between game design and anxiety reduction, ultimately guiding the development of educational games that are more effective at addressing mathematics anxiety for both genders.

As such, if developers intend to target maths games by gender, it might be worth considering more carefully the game-related factors affecting mathematics anxiety. This is particularly important for high school and primary school level students where the gender gap in mathematics anxiety is more significant (Devine et al. 2012; Stoet et al., 2016). For this study, females were particularly concerned with unexpected jumps in difficulty in terms of maths problems, and felt the game could be improved with a more progressive levelling system.

7.2.3.3. Nationality

Despite the small sample size, there was some correlation between nationality and math anxiety from the researcher's study and from research by PISA (OECD, 2023), including high mathematics anxiety amongst Mexican and Romanian students, with Chinese and Singaporean students near the middle or lower end of the scale. The only contrast was that British students had much lower mathematics anxiety overall from PISA study, but were overall in the middle compared to other nationalities in this researcher's study. For educational game developers, if targeting particular nationalities, it may be worth tuning features to cater to countries with different mathematics anxiety levels, this to avoid students from some countries finding the game too difficult, while others, as we've seen with low mathematics anxiety participants, finding the game too boring and reducing replayability.

7.2.3.4. Last maths qualification

Participants with more recent qualifications in maths were found to possess higher mathematics anxiety scores, this may have been due to the shorter sample size. This contradicted most studies, which suggest increased maths avoidance leads to higher mathematics anxiety and vice versa (Anderson 2007; Rawley, 2007; Ganesan, 2017).

Explanation of the unexpected relationship between recent maths qualifications and maths anxiety

One possible explanation is contextual. Many older-qualification participants at Sheffield are mature entrants enrolled in foundation-year math courses, where math anxiety has been explicitly identified as a barrier to progression (Marshall et al., 2017) and targeted support is provided. These students may thus benefit from such interventions, whereas recent school-leavers with fresher qualifications may not yet have accessed this support and may still experience acute exam-related stress. Age-related factors might also contribute, for example, Baloglu and Koçak (2006) found that older undergraduates often report higher math test anxiety than younger peers, suggesting that experience and educational context can alter how anxiety manifests. Together, these factors suggest our unexpected pattern reflects the specific student demographics and support structures at Sheffield.

One might question whether the observed anxiety differences simply reflect age rather than qualification recency. Indeed, prior studies suggest math anxiety tends to rise with age in education: for example, Marshall et al. (2017) note that mathematics anxiety is "particularly prevalent in mature students", and Cho and Kongo (2024) similarly report older undergraduates reporting higher math anxiety than younger peers. Our data likewise showed mature entrants with somewhat higher mean anxiety than recent school-leavers, c

onsistent with these trends. Crucially, however, this age difference did not explain the unexpected qualification–anxiety effect: even among younger students, those with recent math study still exhibited elevated anxiety, whereas some older students did not. In short, age correlates with math anxiety (Cho & Kongo, 2024), but it appears to play only a limited role in the specific results of our study.

7.2.3.4.1. Recent maths qualifications - implications for theory and practice

Contrary to prior studies, our findings carry important implications for both theory and practice. Theoretically, these results challenge the assumption that extended mathematics study uniformly lowers anxiety, instead highlighting how contextual factors (such as targeted support) can moderate the relationship between qualifications and math anxiety (Tariq et al., 2013; Dowker et al., 2016). This suggests that models of math anxiety should be refined to account for educational context and interventions, rather than assuming all students with advanced qualifications will necessarily experience less anxiety. Practically, the pattern we observed indicates a need for proactive support among recent school-leavers who may still be highly anxious. In particular, universities could extend math anxiety interventions, similar to those embedded in foundation-year courses for mature entrants, to younger incoming students, helping them build confidence and reduce anxiety early in their studies (Marshall et al., 2017). Such measures would ensure that students with fresh qualifications are not overlooked, bridging the support gap and potentially aligning their anxiety levels more closely with those of peers who have benefitted from anxiety-reduction initiatives.

7.2.3.5. General anxiety

As already stated, the diary study questionnaire asked participants to rate bot their feelings of mathematics anxiety and their general feelings of anxiety that day, with both using a 1-10 scale (see section 6.1). It was found that general anxiety was overall higher than mathematics anxiety over the 30 days, furthermore whenever general anxiety peaked or dropped mathematics anxiety would follow the same trend. For game developers, little can be done about this, except utilise the list of potential scenarios in the Study 2 portion of this study to base the games on. The exposure to these environments in a virtual environment would not only be more relatable and thus quicker to grasp and engage with for students but can also help improve transfer when participants encounter these scenarios in real life (Palmer & Ham, 2017; Myers II et al., 2018).

8. Conclusion

8.1. Research objectives

This study has carried out the following research objectives. These were addressed in the previous chapter, and a brief summary is presented below.

8.1.1. Review the literature to identify mathematics anxiety scales and computer games that could potentially be used for data collection.

A review of the literature was carried out identifying possible mathematics anxiety scales to use. The 30 item MARS-Brief by (Suinn & Winston, 2003) was chosen due to its known reliability and validity, shorter number of questions as compared to the original (Richardson & Suinn, 1972) 98-item MARS scale, as well as its target demographic of college and University students. A search was also conducted for games to use as potential treatments for the study. The search revealed there were very few browser-based mini-games aimed at adults that teach mathematics. Games were chosen from BBC Skillwise, as these are aimed at adult audiences. Algebra Meltdown from Mangahigh.com was also chosen as it is aimed at all ages. However due to their discontinuation, Mangahigh.com developers recommended Bubble Function for use with Study 4, due to combining a wide range of maths topics taught in one game.

8.1.2. Investigate how mathematics is used in the everyday lives of university students.

A questionnaire was distributed to students at the University of Sheffield, asking what activity they undertook that day that involved mathematics. This part of the study was conducted due to Study 1 respondents stating they felt more confident with maths games with relatable scenarios. The majority of respondents cited shopping, managing personal finances, and planning events as the activity involving maths with arithmetic as the mathematics topic. Such activities have been incorporated into strategy and simulation games before and could be included in a new game with the aim to reduce mathematics anxiety aimed at university students.

8.1.3. Investigate the impact of educational games on mathematics anxiety in university students.

In Study 4, pre-game and post-game mathematics anxiety scores showed mean mathematics anxiety dropped by 13% among the sample over the 30-day period.

8.1.4. Identify game attributes that impact mathematics anxiety.

A fish-bone model was constructed showing the various attributes of games to consider when developing educational games with the aim of reducing mathematics anxiety. This was based on the triangulation of diary study, interview and gameplay observation data, discovering the presentation of maths problems, difficulty changes, game mechanics and the user interface all impacted mathematics anxiety the most.

8.2. Evolution of research process

While the research objectives have remained relatively stable, the approach to data collection has changed significantly throughout the study.

Study 1 was conducted discovering a preference amongst participants for two of the three games for further use in Study 2, 3 and 4 (Algebra Meltdown and Giving Change).

Study 1, while providing an in depth look at the elements of the game that affect usability and anxiety levels has its limitations. The convenience sample represents students from just one area of study (i.e. Information School), when used as an indicator of which game to use for Study 4, this could be open to bias in responses. When determining which game to use, a larger number of students from a wider range of disciplines would have helped remove some potential bias from the data, providing a more complete conclusion.

Results from Study 1 as well as changes to the games availability, new equipment and the availability of participants, meant Study 4 data collection was changed significantly. Algebra Meltdown was no longer available on the developer's server due to a lack of popularity among the company's player base, and Bubble Function was recommended as a suitable alternative. Had Algebra Meltdown been used the results have may have been slightly different: however, the four main attributes of the games that mathematics anxiety between Algebra Meltdown and Bubble Function remain very similar, that is the Game Interface, Game Structure, Problem Solving and Difficulty Levels. Future studies may want to examine this with more participants, though it is unclear even with a larger sample whether the researcher will yield any useful results.

8.3. Contribution to knowledge

8.3.1. Ishikawa model of factors that impact mathematics anxiety in university students

While many studies examine factors that impact on mathematics anxiety, no studies analysing game factors that affect anxiety have been identified: in particular there are no studies structuring these factors into one diagram. The model, accompanied by brief explanations of each factor, can be used as a guide by educational game designers as factors to consider when designing and marketing their games.

8.3.2. Model of everyday mathematics experienced by university students

Results of Study 2 data had similarities to results reported by studies surveying the wider population. The more common mathematics activities were counting, measuring and predicting, and the most uncommon activities took the form of locating, designing, explaining. The emergence of the Predicting category, which encompasses activities such as estimating physical dimensions, cost approximations, and time estimations, suggests an expansion of Bishop's (1988) framework. The adapted model (Table 13) can be used by future researchers. The sample size means study 2 is not generalizable, however this research revealed a variety of mathematics related activities which could lead to further studies of other populations.

The results are important for two reasons. It is now understood the kind of activities involving mathematics that students are exposed to daily, that may seem routine. Discovering relatable real-world activities involving mathematics to incorporate into a game has provided a list of scenarios for developers to select from. Furthermore, in the absence of computer games, teachers could incorporate simulations, roleplays or more simply provide examples of these activities in their classes as a way of demonstrating real world application for abstract mathematics topics.

The second implication is that despite such a specific demographic of students (i.e. UOS students), the everyday mathematics carried out is not dissimilar from the rest of the global population. It could be that incorporating similar activities into games aimed at a wider audience may be effective in reducing mathematics anxiety, improving learning, or perhaps to an extent, increasing engagement amongst players.

8.4. Methodological contribution

8.4.1. Trends in mathematics anxiety and eye movement in computer games

Many studies analyse trends between general anxiety and eye-movement. However, few studies attempt to identify trends between mathematics anxiety and eye movement, particularly in relation to computer games. Here it was demonstrated that participants with high mathematics anxiety tend to spend more time gazing at maths problems, rather than possible solutions available on screen, indicating a shortage of working memory is hindering their ability to solve their problem presented.

8.4.2. Mathematics anxiety scale adapted to UK students

Originally aimed at US college students, the mathematics anxiety scale used for the study was adapted to UK students. This was done by changing US terms such as "math" to "maths", "$" to "£", "sales tax" to "VAT" etc. Questions about the revised scale (according to the interview transcripts), revolved around what kind of anxiety does the scale test, as items appeared to involve test anxiety or performance anxiety too. In general, participants understood the questions and thus the scale could be used for future studies assessing mathematics anxiety in university students.

By grounding design, sampling, measurement, and analysis choices in established research, this study demonstrates how theoretically informed justifications can guide practical experimentation in educational settings. Each methodological decision, from using a validated anxiety scale to integrating mixed-methods analysis, was explicitly aligned with precedent in the literature, strengthening both validity and replicability.

8.5. Limitations

8.5.1. Generalisability and data sufficiency

One concern may be the generalisability of its findings. It is important to clarify that this research was not designed to produce findings that are universally generalisable. Instead, the study aimed to develop a preliminary understanding of how educational games might influence mathematics anxiety in a specific context: university students at the University of Sheffield. This focused approach allowed for a deeper exploration of individual and contextual factors that may not be evident in broader, less targeted studies.

The decision not to aim for generalisability was driven by several considerations:

8.5.1.1. Exploratory nature

This research was designed as an exploratory study to test the feasibility of using educational games to address mathematics anxiety. Its primary goal was to identify trends, develop an initial model, and highlight areas for further investigation, rather than to provide definitive conclusions applicable to all populations.

8.5.1.2. Resource constraints

Practical constraints, such as time and resources, limited the scope of participant recruitment. These limitations necessitated a smaller, more focused sample, which inherently reduces the generalisability of the findings but allows for more manageable and detailed data collection.

Cultural and demographic representation

While the study achieved diversity in participant backgrounds, representing nine different nationalities, the overall sample size of seventeen limited the extent to which cultural differences could be meaningfully analysed. Most nationalities were represented by only a single participant, preventing any reliable statistical comparison across groups. As such, findings related to nationality should be interpreted with caution and not generalised beyond the scope of this sample.

8.5.1.3. Value of the findings

Although not intended to be generalisable, the findings of this study hold significant value:

Model development

The study contributes a novel framework for understanding the impact of educational games on mathematics anxiety. This model can serve as a foundation for further research and refinement in diverse contexts.

Practical implications

The insights derived from this research provide actionable guidance for educators and game developers seeking to address mathematics anxiety within similar populations.

Basis for future studies

By identifying key variables and methodological approaches, this study lays the groundwork for larger-scale research that can test and validate the findings in broader settings.

8.6. Recommendations for future research

8.6.1. Testing the fishbone model

To build on the insights generated by this study, future research should test the validity of the fishbone model, to identify its value in game design and game evaluation. This should include participants from multiple institutions and diverse cultural backgrounds to test the applicability of the model.

8.6.2. Research into everyday mathematics

Further research should investigate whether the new model (see Table 13) agrees with the mathematical activities carried out in countries far different to Western culture, as this was a concern by the author of the original model (Bishop, 1988).

This study limited activities to outside school or work to emphasize more common activities that a wider demographic may experience (such as shopping). Further studies involving university students may wish to consider mathematics activities on their course and jobs.

8.6.3. Alternative gaming platforms

As discovered from the literature, some studies involve participants playing console-based games. Console games differ in that they require a television to play instead of a computer with the keyboard. In this study participants with high mathematics anxiety stated that using having to memorise the keys on a keyboard to play a game would increase their anxiety which in turn would have impacted their mathematics anxiety. Installing and playing games on a PC demands more steps and more technical knowledge then installing a game on a computer. This in turn may invoke computer anxiety which could lead to increased mathematics anxiety (Owolabi et al. 2014).

8.6.4. Use of facial emotion recognition tools

Before the start of Study 4, Facereader software was introduced into the university usability lab where the researcher's study took place. Facial emotions were recorded at the same time as the eye-tracking, with the intention of identifying which facial expression is associated with mathematics anxiety. However, no correlation was found between events in the game, or occurring maths problems and facial expressions, thus the data was discarded. This may have been due to the small sample and diverse range of participants used for the study. Studies with a quantitative focus and larger sample sizes may want to replicate the study with Facereader software as there may be more noticeable trends in the data.

8.6.5. Comparison of cartoon graphics with realistic graphics

As stated in the discussion of transfer (see 7.1.3.3), some participants in the study stated a preference for cartoony over realistic graphics. This conflicts with findings of previous research into everyday maths, where the more realistic the environment the more effect students learn and transfer their learning into their everyday life. A future study could be conducted to explore student preferences and engagement in more depth. This will help determine the direction to go in terms of graphical environment of the game.

8.6.6. List of potential scenarios for maths games for reducing mathematics anxiety

From the everyday mathematics data, several common activities that students carry out on a daily basis that involve mathematics were identified, namely Shopping, Management Personal Finances, Planning Events, Cooking. One or many could be used as scenarios in games and due to being in a relatable environment carrying out similar tasks that students are familiar with, should reduce mathematics anxiety in equivalent real-life scenarios.

8.6.7. Use games with multiple everyday maths activities

Furthermore, the game chosen for Study 4 does not encompass an everyday mathematics activity, but rather the Candy Crush or similar format of game that students are known to be familiar with or at least aware of already. Aside from the mobile game used in Study 3, the alternative mini-games used throughout Study 3 encompass a single everyday activity. Studies researching mathematics anxiety may want to further analyse the impact of mathematics games featuring multiple everyday activities, as these may reduce mathematics anxiety further.

8.7. Recommendations for practice

8.7.1. Use of everyday scenarios

In terms of the potential in game storylines, there appears to be a wide range of relatable activities and mathematical concepts to draw from. Some of these could be combined into one game to increase depth of content (as suggested by participants in Study 1). When conducting observations and interviews on students playing mathematics games, attention should be paid to the presentation of storylines, such as whether participants prefer activities presented with a cartoonish appearance/mechanics or whether participants engage more with a realistic simulated environment.

From the everyday mathematics data, several common activities that students carry out on a daily basis that involve mathematics were identified, namely Shopping, Management Personal Finances, Planning Events, Cooking. One or many could be used as scenarios in games and due to being in a relatable environment carrying out similar tasks that students are familiar with, should reduce mathematics anxiety in equivalent real-life scenarios.

8.7.2. Use games aimed at adult age groups

The majority of Study 4 participants perceived the Bubble Function as being aimed at children, and indeed the game and the collection of the games designed by the Mangahigh publisher are aimed at 7-16 year olds. That said the site does state that "…anyone with a desire to improve their Mathematics ability can join Mangahigh.com and will benefit from it." therefore the games should be somewhat playable for anyone. In interviews however, participants made reference to games that mainly teens and adults would play, such as X-Com, World of Warcraft (both aimed at 13+ year olds), these participants also have found the Bubble Function game boring, repetitive and were not interested in playing the game in their spare time. Other participants who played Candy Crush and similar mobile games, however had no issue with the perceived target age and challenge variety of the game, found Bubble Function engaging and stated that they would play in their free time. For developers, this means if attempting to attract PC and console players the game should have a wider range of challenges (both in terms of game mechanics) as well as more teen or adult themes and scenarios to keep them interested. For mobile however, it appears no changes to the content in terms of target age is needed.

8.8. Summary

This research aimed to develop a model identifying game attributes that impact mathematics anxiety, based on four empirical studies conducted with students at the University of Sheffield. The findings support the conclusion that certain educational game features such as adjustable difficulty levels, contextual relevance, and a psychologically safe learning environment can help reduce feelings of anxiety associated with mathematics tasks.

These conclusions are supported by broader research evidence. Meta-analyses by Gui et al. (2023) and Sammallahti et al. (2023) indicate that structured digital games and cognitive-emotional interventions respectively lead to moderate improvements in learning and anxiety outcomes. Although Dondio et al. (2023) found only small and statistically insignificant effects from digital games alone, their work emphasises the need for games to be explicitly designed with anxiety-reducing mechanisms in mind. These include features that manage challenge levels dynamically, provide formative feedback, and foster a "safe-to-fail" environment. Tene et al. (2025) also highlight that serious games, when implemented with appropriate scaffolding, increase motivation and knowledge retention despite technical and pedagogical challenges.

The evidence presented in this thesis suggests that while educational games alone may not be a panacea, they can be an effective component within a broader set of strategies for addressing mathematics anxiety particularly when embedded in a pedagogically sound, emotionally supportive, and context-sensitive framework. The game attributes identified in the proposed model are aligned with empirically validated mechanisms, including cognitive load management, emotional regulation, and situational engagement.

Nonetheless, limitations of the current research include the constrained demographic scope, the relatively short intervention durations, and the limited diversity of game genres tested. These factors restrict the generalisability and ecological validity of the findings. Future research should involve larger, more diverse populations, longer interventions, and comparative testing of different game formats. Additionally, integrating facial emotion recognition and physiological measures could enrich the analysis of real-time anxiety responses during gameplay.

In conclusion, this thesis affirms the promise of well-designed educational games as anxiety-aware learning interventions. When grounded in evidence-based design principles and tailored to learners' emotional and cognitive needs, such games can play a valuable role in addressing mathematics anxiety in higher education settings. This study has demonstrated the significant potential of educational computer games in reducing mathematics anxiety among university students. Through the use of mixed-method approaches, including observational studies, and tools for measuring real-time anxiety responses, this research has identified key game attributes that effectively reduce anxiety and developed a robust model for designing future interventions. The findings emphasise the value of incorporating real-life contexts, customisable difficulty levels, and user-centred design to enhance engagement and alleviate anxiety. In addition to providing a framework for educators and game developers to create impactful tools, this study offers important insights into the complex relationship between educational technology and emotional barriers to learning. By addressing gaps in existing research and practice, this work lays the groundwork for scalable, inclusive, and evidence-based strategies to improve learning experiences and outcomes.

9. Bibliography

Abdulmajed, H., Park, Y. S., & Tekian, A. (2015). Assessment of educational games for health professions: A systematic review of trends and outcomes. *Medical Teacher, 37*(sup1), S27–S32.

Abraham, M., Aishwarya, R., & Rajendran, S. (2017). Prevalence and intensity of general anxiety and mathematics anxiety in college students. *International Journal of Pure and Applied Mathematics, 114*(12), 11–20.

Achim, N., & Al Kassim, A. (2015). Computer usage: The impact of computer anxiety and computer self-efficacy. *Procedia – Social and Behavioral Sciences, 172*, 701–708.

Adikari, S., McDonald, C., & Collings, P. (2006, November). A design science approach to an HCI research project. In *Proceedings of the 18th Australia Conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments* (pp. 429–432).

Alkhateeb, H. M. (2004). Internal consistency reliability and construct validity of an Arabic translation of the shortened form of the Fennema-Sherman Mathematics Attitudes Scales. *Psychological Reports, 94*(2), 565–571.

Allen, M. (2017). *The SAGE encyclopedia of communication research methods*. Sage Publications.

Altun, M., Yılmaz, G. K., Demir, B., & Çelik, H. S. (2021). Statistical anxiety and metacognitive awareness levels of graduate students studying in mathematics education program. *European Journal of Education Studies, 9*(1).

Anastasiadis, T., Lampropoulos, G., & Siakas, K. (2018). Digital game-based learning and serious games in education. *International Journal of Advances in Scientific Research and Engineering (IJASRE), 4*(12), 139–144.

Anderson, B., & Fagerhaug, T. (2000). *Root cause analysis: Simplified tools and techniques*. ASQ Quality Press.

Anindyarini, R., & Supahar, S. (2019). Portrait of mathematical anxiety in early youth ages. *International Journal of Trends in Mathematics Education Research, 2*(3), 128–132.

Ashcraft, M. H., & Faust, M. W. (1994). Mathematics anxiety and mental arithmetic performance: An exploratory investigation. *Cognition & Emotion, 8*(2), 97–125.
Ashcraft, M. H., & Kirk, E. P. (2001). The relationships among working memory, math anxiety, and performance. *Journal of Experimental Psychology: General, 130*(2), 224–227.

Ashcraft, M. H., & Krause, J. A. (2007). Working memory, math performance, and math anxiety. *Psychonomic Bulletin & Review, 14*, 243–248.

Ashcraft, M. H., & Moore, A. M. (2009). Mathematics anxiety and the affective drop in performance. *Journal of Psychoeducational Assessment, 27*(3), 197–205.

Backlund, P., & Hendrix, M. (2013). Educational games–are they worth the effort? A literature survey of the effectiveness of serious games. *Games and Virtual Worlds for Serious Applications (VS-GAMES) 2013*, 1–8.

Baloğlu, M., & Zelhart, P. F. (2003). Statistical anxiety: A detailed review of the literature. *Psychology and Education, 40*(2), 27–37.

Barber, T. J. (2019). Why gamification doesn't mean serious games [Blog]. Dashine & Thomson.

Bessant, K. C. (1995). Factors associated with types of mathematics anxiety in college students. *Journal for Research in Mathematics Education*, 327–345.

Bhasin, K. (2014, January 14). Gamification, game-based learning, serious games – any difference? Retrieved from [link not provided].

Bhattacharya, S., Bashar, M. A., Srivastava, A., & Singh, A. (2019). Nomophobia: No mobile phone phobia. *Journal of Family Medicine and Primary Care, 8*(4), 1297–1301.

Bicheno, J., & Holweg, M. (2009). *The lean toolbox: The essential guide to lean transformation*. PICSIE Books.

Birenbaum, M., & Eylath, S. (1994). Who is afraid of statistics? Correlates of statistics anxiety among students of educational sciences. *Educational Research, 36*(1), 93–98.

Blazer, C. (2011). Strategies for reducing math anxiety. *Information Capsule, 1102.* Research Services, Miami-Dade County Public Schools.

Bonne, M. (2010). *Conceptual mini-games: An effective e-learning resource?* [Unpublished Master's dissertation, University of Sheffield]. Retrieved from http://dagda.shef.ac.uk/dispub/dissertations/2009-10/External/Mbonne_bonne_090125661.pdf

Boyle, E. A., Hainey, T., Connolly, T. M., Gray, G., Earp, J., Ott, M., Lim, T., Ninaus, M., Ribeiro, C., & Pereira, J. (2016). An update to the systematic literature review of empirical evidence of the impacts and outcomes of computer games and serious games. *Computers & Education, 94*, 178–192.

Bruggers, C. S., Baranowski, S., Beseris, M., Leonard, R., Long, D., Schulte, E., Shorter, A., Stigner, R., Mason, C. C., Bedrov, A., & Pascual, I. (2018). A prototype exercise–empowerment mobile video game for children with cancer, and its usability assessment: Developing digital empowerment interventions for pediatric diseases. *Frontiers in Pediatrics, 6*, 69.

Buck, J. L. (1987). More on superiority of women in statistics achievement: A reply to Brooks. *Teaching of Psychology, 14*(1), 45–46.

Buckley, P., & Doyle, E. (2016). Gamification and student motivation. *Interactive Learning Environments, 24*(6), 1162–1175.

Butterworth, B., & Laurillard, D. (2010). Low numeracy and dyscalculia: Identification and intervention. *ZDM, 42*(6), 527–539.

Bylieva, D., & Sastre, M. (2018). Classification of educational games according to their complexity and the player's skills. *The European Proceedings of Social & Behavioural Sciences, LI*, 1–2014. https://dx.doi.org/10.15405/epsbs.2018.12.02.47

Bryant, C. G. A. (1985). *Positivism in social theory and research*. Macmillan.

Byrd, P. (1982). *A descriptive study of mathematics anxiety: Its nature and antecedents* [Unpublished doctoral dissertation]. Indiana University.

Çankaya, S., & Karamete, A. (2009). The effects of educational computer games on students' attitudes towards mathematics course and educational computer games. *Procedia – Social and Behavioral Sciences, 1*(1), 145–149.

Carter, C., & Erna, Y. (2017). Math anxiety in the science classroom. *The Hoosier Science Teacher, 40*(1), 27–32.

Castillo, R. E., Cheng, C. J., Agustin, J. S., & Aragon, M. C. R. (2019). Development of an educational mobile game for grade 5 for Knowledge Channel Inc. In *Proceedings of the 2019 2nd International Conference on Information Science and Systems*, 99–104.

Cavanagh, S. (2007). Math anxiety confuses the equation for students. *Education Week, 26*(24), 12.

Cazan, A.-M., Cocoradă, E., & Maican, C. I. (2016). Computer anxiety and attitudes towards the computer and the internet with Romanian high-school and university students. *Computers in Human Behavior, 55*, 258–267.

Chaman, M., & Callingham, R. (2013). Relationship between mathematics anxiety and attitude towards mathematics among Indian students. *Mathematics Education Research Group of Australasia*.

ChePa, N., Bakar, N. A. A., & Mohd, A. (2015). Usability evaluation of digital Malaysian traditional games. *Jurnal Teknologi, 77*(29), 85–90.

Cipora, K., Santos, F. H., Kucian, K., & Dowker, A. (2022). Mathematics anxiety—where are we and where shall we go? Annals of the New York Academy of Sciences, 1513(1), 10–20.

Clark, D. B., Tanner-Smith, E. E., & Killingsworth, S. S. (2016). Digital games, design, and learning: A systematic review and meta-analysis. Review of educational research, 86(1), 79-122.

Coccia, M. (2017). The Fishbone diagram to identify, systematize and analyze the sources of general purpose technologies (SSRN Scholarly Paper No. 3100011). Social Science Research Network.

Codiroli McMaster, N. (2019). What role do students' enjoyment and perception of ability play in social disparities in subject choices at university? *British Journal of Sociology of Education, 40*(3), 357–377.

Coştu, S., Aydın, S., & Filiz, M. (2009). Students' conceptions about browser-game-based learning in mathematics education: TTNetvitamin case. *Procedia – Social and Behavioral Sciences, 1*(1), 1848–1852.

Cottee, M., Relph, A., & Robins, K. (2013). Supporting students making the transition from school to university: A national and local view of the maths skills crisis in the UK. In *Proceedings of the 6th International Conference on Education and New Learning Technologies (EDULEARN13)* (pp. 6431–6440).

Crawley, D. (2015, June 24). Making educational games is tough, especially if you want to make money. VentureBeat. Retrieved from https://venturebeat.com/2015/06/24/making-educational-games-is-tough-especially-if-you-want-to-make-money/

Cruise, R. J., Cash, R. W., & Bolton, D. L. (1985). Development and validation of an instrument to measure statistical anxiety. *Behavioral Sciences, 4*(3), 92–97.

Cui, J., Zhang, Y., Cheng, D., Li, D., & Zhou, X. (2017). Visual form perception can be a cognitive correlate of lower level math categories for teenagers. *Frontiers in Psychology, 8*, 1336.

Curtain-Phillips, M. (2001). The causes and prevention of mathematics anxiety. *[Publication/source not specified]*.

Dahalan, F., Alias, N., & Shaharom, M. S. N. (2024). Gamification and game-based learning for vocational education and training: A systematic literature review. *Education and Information Technologies, 29*, 1279–1317.

De Jans, S., Van Geit, K., Cauberghe, V., Hudders, L., & De Veirman, M. (2017). Using games to raise awareness: How to co-design serious mini-games? *Computers & Education, 110*, 77–87.

De Lange, J. (2003). Mathematics for literacy. In *Quantitative Literacy: Why Numeracy Matters for Schools and Colleges* (p. 80–89).

De Winter, J. C. F., Zadpoor, A. A., & Dodou, D. (2014). The expansion of Google Scholar versus Web of Science: A longitudinal study. *Scientometrics, 98*(2), 1547–1565.

Dele-Ajayi, O., Sanderson, J., Strachan, R., & Pickard, A. (2016). Learning mathematics through serious games: An engagement framework. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–5).

Deri, R. R., Nugroho, I. S., & Nahwan, D. (2020). Analysis of quality management system in the textile industry with the 5R/5S method and fish bone diagram. *Prosiding ICoISSE, 1*(1), 859–871.

DiSalvo, B. J., Crowley, K., & Norwood, R. (2008). Learning in context: Digital games and young black men. *Games and Culture, 3*(2), 131–141.

Divjak, B., & Tomić, D. (2011). The impact of game-based learning on the achievement of learning goals and motivation for learning mathematics – a literature review. *Journal of Information and Organizational Sciences, 35*(1), 15–30.

Dondio, P., Gusev, V., & Rocha, M. (2023). Do games reduce maths anxiety? A meta-analysis. *Computers & Education, 194*, 104650.

Dowker, A. (2019). *Individual differences in arithmetic: Implications for psychology, neuroscience and education*. Routledge.

Dowker, A., Sarkar, A., & Looi, C. Y. (2016). Mathematics anxiety: What have we learned in 60 years? *Frontiers in Psychology, 7*, 508.

Drachen, A., Mirza-Babaei, P., & Nacke, L. E. (2018). *Games user research*. Oxford University Press.

Dreger, R. M., & Aiken Jr, L. R. (1957). The identification of number anxiety in a college population. *Journal of Educational Psychology, 48*(6), 344–348.

Drobics, M., & Smith, S. (2014). Game-based IT solutions for active and healthy aging. *Proceedings of the 8th International Conference on Serious Games (SeGAH)*, 8–11.

Edwards, A. R., Esmonde, I., & Wagner, J. F. (2011). Learning mathematics. In S. M. Turner (Ed.), *Handbook of Research on Learning and Instruction* (pp. 69–91). Routledge.

Erhel, S., & Jamet, E. (2013). Digital game-based learning: Impact of instructions and feedback on motivation and learning effectiveness. *Computers & Education, 67*, 156–167.

Ersozlu, Z. (2024). Technology-based approaches to reduce mathematics anxiety: A systematic literature review. *Contemporary Educational Technology, 16*(3), Article ep517.

ESA. (2012). *2012 Essential facts about the computer and video game industry*. Retrieved from https://www.slideshare.net/tinhanhvy/essential-facts-about-the-computer-and-video-game-industry-2012

ESA. (2019). *2019 Essential facts about the computer and video game industry*. Retrieved from https://www.theesa.com/wp-content/uploads/2019/05/2019-Essential-Facts-About-the-Computer-and-Video-Game-Industry.pdf

Fennema, E., & Sherman, J. A. (1976). Fennema-Sherman mathematics attitudes scales: Instruments designed to measure attitudes toward the learning of mathematics by females and males. *Journal for Research in Mathematics Education*, 324–326.

Field, A. P., Evans, D., Bloniewski, T., & Kovas, Y. (2019). Predicting maths anxiety from mathematical achievement across the transition from primary to secondary education. *Royal Society Open Science, 6*(11), 191459.

Fortin, L., Marcotte, D., Diallo, T., Potvin, P., & Royer, É. (2013). A multidimensional model of school dropout from an 8-year longitudinal study in a general high school population. *European Journal of Psychology of Education, 28*(2), 563–583.

Freedman, E. (2010). *Ten ways to reduce math anxiety*. Retrieved November 7, 2010.

Frias-Navarro, D., Monterde-i-Bort, H., Navarro-Gonzalez, N., Molina-Palomero, O., Pascual-Soler, M., PerezGonzalez, J., & Longobardi, C. (2018). Statistics anxiety in university students in assessment situations. *Procedia – Social and Behavioral Sciences, 237*, 337–345.

Furner, J. M., & Berman, B. T. (2003). Math anxiety: Overcoming a major obstacle to the improvement of student math performance. *Childhood Education, 79*(3), 170–174.

Gan, S. K.-E., Lim, K. M.-J., & Haw, Y.-X. (2016). The relaxation effects of stimulative and sedative music on mathematics anxiety: A perception-to-physiology model. *Psychology of Music, 44*(4), 730–741.

Gao, N., Xie, T., & Liu, G. (2018). A learning engagement model of educational games based on virtual reality. In *2018 International Joint Conference on Information, Media and Engineering (ICIME)* (pp. 1–5).

Garcia-Ruiz, M. A. (2017). *Games user research: A case study approach*. CRC Press.

Gathercole, S. E., & Alloway, T. P. (2007). *Understanding working memory: A classroom guide*. Harcourt Assessment.

Gaudron, J.-P., & Vignoli, E. (2002). Assessing computer anxiety with the interaction model of anxiety: Development and validation of the computer anxiety trait subscale. *Computers in Human Behavior, 18*(3), 315–325.

Geist, E. (2010). *The anti-anxiety curriculum: Combating math anxiety in the classroom*. Journal of Instructional Psychology, 37(1).

Girard, C., Ecalle, J., & Magnan, A. (2013). Serious games as new educational tools: How effective are they? A meta-analysis of recent studies. *Journal of Computer Assisted Learning, 29*(3), 207–219.

Gomes, A., & Mendes, A. J. (2007). Learning to program – difficulties and solutions. In *Proceedings of the 2007 International Conference on Engineering Education–ICEE, 2007*.

González, A., Rodríguez, Y., Faílde, J. M., & Carrera, M. V. (2016). Anxiety in the statistics class: Structural relations with self-concept, intrinsic value, and engagement in two samples of undergraduates. *Learning and Individual Differences, 45*, 214–221.

Gresham, G., Sloan, T., & Vinson, B. (1997). Reducing mathematics anxiety in fourth grade “at-risk” students. ERIC Clearinghouse.

Griffiths, M. D. (2002). The educational benefits of videogames. *Education and Health, 20*(3), 47–51.

Haberstroh, S., & Schulte-Körne, G. (2019). The diagnosis and treatment of dyscalculia. *Deutsches Ärzteblatt International, 116*(7), 107.

Habgood, M. J., & Ainsworth, S. E. (2011). Motivating children to learn effectively: Exploring the value of intrinsic integration in educational games. The Journal of the Learning Sciences, 20(2), 169-206.

Hall, C. (2020, January 22). Tabletop gaming dominated Kickstarter in 2019 [Entertainment News]. *Polygon*. Retrieved from https://www.polygon.com/2020/1/22/21068797/kickstarter-2019-board-games-video-games-tabletop-data-china-tariffs-trump

Haralson, K. (2002). *Math anxiety: Myth or monster*. Indiana University of Pennsylvania.

Haynes, S. E. (2004). The effect of background music on the mathematics test anxiety of college algebra students [Doctoral dissertation, West Virginia University].

Heinssen, R. K., Glass, C. R., & Knight, L. A. (1987). Assessing computer anxiety: Development and validation of the computer anxiety rating scale. *Computers in Human Behavior, 3*(1), 49–59.

Hellhammer, D. H., Wüst, S., & Kudielka, B. M. (2009). Salivary cortisol as a biomarker in stress research. *Psychoneuroendocrinology, 34*(2), 163–171.

Hellum-Alexander, A. (2010). Effective teaching strategies for alleviating math anxiety and increasing self-efficacy in secondary students. *[Unpublished manuscript]*.

Hembree, R. (1990). The nature, effects, and relief of mathematics anxiety. *Journal for Research in Mathematics Education, 21*(1), 33–46.

Higgins, J. P., & Green, S. (2008). *Cochrane handbook for systematic reviews of interventions* (Version 5.0.0). Wiley.

Hill, F., Mammarella, I. C., Devine, A., Caviola, S., Passolunghi, M. C., & Szűcs, D. (2016). Maths anxiety in primary and secondary school students: Gender differences, developmental changes and anxiety specificity. *Learning and Individual Differences, 48*, 45–53.

Hillman, S., Stach, T., Procyk, J., & Zammitto, V. (2016). Diary methods in AAA games user research. In *Proceedings of the 2016 ACM Conference on Eye Tracking Research & Applications* (pp. 1879–1885).

Hodgen, J., McAlinden, M., Tomei, A., & The Higher Education Academy. (2014). *Mathematical transitions: A report on the mathematical and statistical needs of students undertaking undergraduate studies in various disciplines*. https://www.heacademy.ac.uk/sites/default/files/resources/HEA_Mathematical-transitions_webv2.pdf

Hoorfar, H., & Taleb, Z. (2015). Correlation between mathematics anxiety and metacognitive knowledge. *Procedia – Social and Behavioral Sciences, 182*, 737–741.

Hopko, D. R. (2003). Confirmatory factor analysis of the math anxiety rating scale–revised. *Educational and Psychological Measurement, 63*(2), 336–351.

Hopko, D. R., Mahadevan, R., Bare, R. L., & Hunt, M. K. (2003). The abbreviated math anxiety scale (AMAS): Construction, validity, and reliability. *Assessment, 10*(2), 178–182.

Hung, C.-M., Huang, I., & Hwang, G.-J. (2014). Effects of digital game-based learning on students' self-efficacy, motivation, anxiety, and achievements in learning mathematics. *Journal of Computers in Education, 1*(2–3), 151–166. https://doi.org/10.1007/s40692-014-0008-8

Hunt, T. E., Bagdasar, O., Sheffield, D., & Schofield, M. B. (2019). Assessing domain specificity in the measurement of mathematics calculation anxiety. *Education Research International, 2019*, Article 8258690.

Hunt, T. E., Clark-Carter, D., & Sheffield, D. (2011). The development and part validation of a UK scale for mathematics anxiety. *Journal of Psychoeducational Assessment, 29*(5), 455–466.

Hwang, W., & Salvendy, G. (2010). Number of people required for usability evaluation: The 10±2 rule. *Communications of the ACM, 53*(5), 130–133.

Illanas Vila, A., Gallego-Durán, F. J., Satorre Cuerda, R., & Llorens Largo, F. (2008). Conceptual mini-games for learning. [Conference paper].

Iossi, L. (2013). Strategies for reducing math anxiety in post-secondary students. *[Unpublished manuscript]*.

Ishikawa, K. (1990). *Introduction to quality control* (3rd ed.). Productivity Press.

Jackson, C. D., & Leffingwell, R. J. (1999). The role of instructors in creating math anxiety in students from kindergarten through college. *The Mathematics Teacher, 92*(7), 583–586.

Jackson, E. (2008). Mathematics anxiety in student teachers. *Practitioner Research in Higher Education, 2*(1), 36–42.

Jagušt, T., Botički, I., & So, H.-J. (2018). Examining competitive, collaborative and adaptive gamification in young learners' math learning. *Computers & Education, 125*, 444–457.

Jameson, M. M. (2019). Time, time, time: Perceptions of the causes of mathematics anxiety in highly maths anxious female adult learners. *Adult Education Quarterly*. Advance online publication. https://doi.org/10.1177/0741713619896324

Jay, T., & Betenson, J. (2017). Mathematics at your fingertips: Testing a finger-training intervention to improve quantitative skills. *Frontiers in Education, 2*, 22.

Kangas, M., Koskinen, A., & Krokfors, L. (2017). A qualitative literature review of educational games in the classroom: The teacher's pedagogical activities. *Teachers and Teaching, 23*(4), 451–470.

Kapp, K. M. (2012). *The gamification of learning and instruction*. Wiley.

Karimi, A., & Venkatesan, S. (2009). Mathematics anxiety, mathematics performance and academic hardiness in high school students. *International Journal of Educational Sciences, 1*(1), 33–37.

Karimi, B. (2008). Development of mathematics anxiety scales in high school students of India and Iran [Unpublished doctoral thesis]. University of Mysore, India.

Kazelskis, R. (1998). Some dimensions of mathematics anxiety: A factor analysis across instruments. *Educational and Psychological Measurement, 58*(4), 623–633.

Ke, F. (2008). Computer games application within alternative classroom goal structures: Cognitive, metacognitive, and affective evaluation. *Educational Technology Research and Development, 56*(5–6), 539–556.

Ke, F. (2013). Computer-game-based tutoring of mathematics. *Computers & Education, 60*(1), 448–457.

Keele, S. (2007). Guidelines for performing systematic literature reviews in software engineering (EBSE Technical Report ver. 2.3). *Engineering of Computer-Based Systems (ECBS) Foundation.*

Kelkar, K. (2020). What sample size do you really need for UX research? [Blog]. Retrieved July 19, 2020, from https://www.userzoom.com/blog/what-sample-size-do-you-really-need-for-ux-research/

Kessler, R. C., Berglund, P., Demler, O., Jin, R., Merikangas, K. R., & Walters, E. E. (2005). Lifetime prevalence and age-of-onset distributions of DSM-IV disorders in the National Comorbidity Survey Replication. *Archives of General Psychiatry, 62*(6), 593–602.

Khan, M. A., Azizah, M., & Ullah, S. (2019). A fractional model for the dynamics of competition between commercial and rural banks in Indonesia. *Chaos, Solitons & Fractals, 122*, 32–46.

Khesht-Masjedi, M. F., Shokrgozar, S., Abdollahi, E., Habibi, B., Asghari, T., Ofoghi, R. S., & Pazhooman, S. (2019). The relationship between gender, age, anxiety, depression, and academic achievement among teenagers. *Journal of Family Medicine and Primary Care, 8*(3), 799–799.

Kindermann, T. A., & Skinner, E. A. (2009). How do naturally existing peer groups shape children's academic development during sixth grade? *International Journal of Developmental Science, 3*(1), 27–38.

Komogortsev, O. V., Jayarathna, S., Koh, D. H., & Gowda, S. M. (2010, March). Qualitative and quantitative scoring and evaluation of eye movement classification algorithms. In *Proceedings of the 2010 Symposium on Eye-Tracking Research & Applications* (pp. 65–68). ACM.

Krinzinger, H., Kaufmann, L., Dowker, A., Thomas, G., Graf, M., Nuerk, H.-C., & Willmes, K. (2007). German version of the math anxiety questionnaire (FRA) for 6- to 9-year-old children. *Zeitschrift für Kinder- und Jugendpsychiatrie und Psychotherapie, 35*(5), 341–351.

Laitinen, S. (2005). Better games through usability evaluation and testing. *Gamasutra.* Retrieved from http://www.gamasutra.com/features/20050623/laitinen_01.shtm

Lahtinen, E., Ala-Mutka, K., & Järvinen, H.-M. (2005). A study of the difficulties of novice programmers. *ACM SIGCSE Bulletin, 37*(4), 14–18.

Landerl, K., Bevan, A., & Butterworth, B. (2004). Developmental dyscalculia and basic numerical capacities: A study of 8–9-year-old students. *Cognition, 93*(2), 99–125.

Law, E. L.-C., & Sun, X. (2012). Evaluating user experience of adaptive digital educational games with Activity Theory. *International Journal of Human-Computer Studies, 70*(7), 478–497.

Lester, J. C., Spires, H. A., Nietfeld, J. L., Minogue, J., Mott, B. W., & Lobene, E. V. (2014). Designing game-based learning environments for elementary science education: A narrative-centered learning perspective. *Information Sciences, 264*, 4–18.

Lim, S. Y., & Chapman, E. (2012). An investigation of the Fennema-Sherman mathematics anxiety subscale. *Measurement and Evaluation in Counseling and Development, 45*(1), 55–63.

Lloyd, B., & Gressard, C. (1986). Gender and amount of computer experience of teachers in staff development programs: Effect on computer attitudes and perceptions of usefulness of computers. *Journal of AEDS (Association for Educational Data Systems), 19*, 302–311.

López-Arcos, J. R., Padilla-Zea, N., Paderewski, P., & Gutiérrez, F. (2017). Designing stories for educational video games: Analysis and evaluation. *International Journal of Web-Based Learning and Teaching Technologies (IJWLTT), 12*(4), 1–13.

Loop11.com. (2020). How many participants should be used for online, quantitative usability testing? Retrieved July 19, 2020, from https://www.loop11.com/how-many-participants/

Lyons, I. M., & Beilock, S. L. (2012). When math hurts: Math anxiety predicts pain network activation in anticipation of doing math. *PLOS ONE, 7*(10), e48076.

Macionis, J. J. (2018). Positivism. In J. M. Martin (Ed.), *Sociology of religion: A reader* (3rd ed., pp. 49–52). Oxford University Press.

Mahmood, S., & Khatoon, T. (2011). Development and validation of the mathematics anxiety scale for secondary and senior secondary school students. *British Journal of Arts and Social Sciences, 2*(2), 169–179.

Makaka, B., Chirimbana, M., & Nghipandulwa, L. (2023). The impact of mathematics anxiety on students' persistence in mathematics courses: A study in the Oshakati Circuit. *Open Journal of Social Sciences, 11*(12), 636–651.

Malik, S. (2014). Undergraduates' statistics anxiety and mathematics anxiety: Are they similar or different constructs? *JSM Proceedings, Survey Research Methods Section*, 809–815.

Maloney, E. A., & Beilock, S. L. (2012). Math anxiety: Who has it, why it develops, and how to guard against it. *Trends in Cognitive Sciences, 16*(8), 404–406.

Manero, B., Torrente, J., Serrano, Á., Martínez-Ortiz, I., & Fernández-Manjón, B. (2015). Can educational video games increase high school students' interest in theatre? *Computers & Education, 87*, 182–191.

Marakas, G. M., Johnson, R. D., & Palmer, J. W. (2000). A theoretical model of differential social attributions toward computing technology: When the metaphor becomes the model. *International Journal of Human-Computer Studies, 52*(4), 719–750.

Marrelli, A. F. (2005). *The performance technologist's toolbox: Literature reviews.* Performance Improvement, 44(7), 40.

Marshall, E. M., Staddon, R. V., Wilson, D. A., & Mann, V. E. (2017). Addressing maths anxiety and engaging students with maths within the curriculum. *MSOR Connections, 15*(3).

Martin, K. R., Rothbaum, B., Carlbring, P., Botella, C., Peskin, M., Loucks, L., & Powers, M. (2018, April). Real world observations using virtual reality treatments for anxiety and related disorders. Paper presented at the Anxiety and Depression Association of America Conference, Washington DC, USA.

Martin, M. W. (2012). *Serious game design principles: The impact of game design on learning outcomes*.

Masingila, J. O. (2002). Examining students' perceptions of their everyday mathematics practice. *Journal for Research in Mathematics Education Monograph*, 30–39.

Mata, M. de L., Monteiro, V., & Peixoto, F. (2012). Attitudes towards mathematics: Effects of individual, motivational, and social support factors. *Child Development Research, 2012*, Article 876028. https://doi.org/10.1155/2012/876028

Mattarella-Micke, A., Mateo, J., Kozak, M. N., Foster, K., & Beilock, S. L. (2011). Choke or thrive? The relation between salivary cortisol and math performance depends on individual differences in working memory and math-anxiety. *Emotion, 11*(4), 1000–1007.

Mavridis, A., Katmada, A., & Tsiatsos, T. (2017). Impact of online flexible games on students' attitude towards mathematics. *Educational Technology Research and Development, 65*(6), 1451–1470.

May, D. K. (2009). *Mathematics self-efficacy and anxiety questionnaire*.

McMullan, M., Jones, R., & Lea, S. (2012). Math anxiety, self‐efficacy, and ability in British undergraduate nursing students. *Research in Nursing & Health, 35*(2), 178–186.

McVitty, D., & Morris, K. (2012). *Never too late to learn: Mature students in higher education*. Report by million+ and National Union of Students.

Meyers, P. J. (2019). How often does Google update its algorithm? Retrieved from https://moz.com/blog/how-often-does-google-update-its-algorithm

Miller, D. J., & Robertson, D. P. (2010). Using a games console in the primary classroom: Effects of 'Brain Training' programme on computation and self-esteem. *British Journal of Educational Technology, 41*(2), 242–255.

Mitchell, A., & Savill-Smith, C. (2004). *The use of computer and video games for learning: A review of the literature*. Learning and Skills Development Agency.

Mohsen, K., Abdollahi, S., & Omar, S. (2019). Evaluating the educational value of simulation games: Learners' perspective. *Innovations in Education and Teaching International, 56*(4), 517–528.

Molnar, A., & Frías-Martínez, V. (2011). Educamovil: Mobile educational games made easy. In *EdMedia+ Innovate Learning Conference Proceedings* (pp. 3684–3689). Association for the Advancement of Computing in Education (AACE).

Molnar, A., Virseda, J., & Frías-Martínez, V. (2015). Insights from Educamovil: Involving teachers in creating educational content for mobile learning games. *Journal of Interactive Learning Research, 26*(2), 209–221.

Moschkovich, J. N. (2002). An introduction to examining everyday and academic mathematical practices. *Journal for Research in Mathematics Education Monograph*, 1–11.
Morris, E. A. (2007). Students' perceptions on the reduction of math anxiety. [Master's thesis, Purdue University]. ProQuest Dissertations Publishing.

Murphy, D. (2018). A phenomenological study of college students in developmental mathematics classes' experiences with mathematics and computer anxiety. *[Doctoral dissertation, University of Alabama].*

Murphy, E. A. (1990). *Evaluating the quality of learning: The SOLO taxonomy (structure of the observed learning outcome)*. Academic Press.

Mutodi, P., & Ngirande, H. (2014). Exploring mathematics anxiety: Mathematics students' experiences. *Mediterranean Journal of Social Sciences, 5*(1), 283–292.

Mweli, P. (2018). Indigenous stories and games as approaches to teaching within the classroom. In *Understanding Educational Psychology* (pp. 94–101).

Nah, F., Zhou, Y., & Boey, A. (2012). User engagement in educational computer gaming. *AIS Transactions on Human-Computer Interaction, 4*. https://aisel.aisnet.org/sighci2012/4

Navarro-Remesal, V., & Zapata, B. P. (2019). First-person refugee games: Ludonarrative strategies for playing the stories of refugees and asylum seekers. *In M. Loyola (Ed.), 1st International Seminar on Education Innovation and Economic Management (SEIEM)* (pp. 3–17).

Ngamntwini, B., & Cilliers, L. (2019). A usability framework for diabetic health applications in South Africa. In *Proceedings of the Future Technologies Conference (FTC) 2018: Volume 2* (pp. 431–443). Springer.

NHS. (2015). *Generalised anxiety disorder in adults*. Retrieved from http://www.nhs.uk/Conditions/Anxiety/Pages/Introduction.aspx

Nielsen, J. (2000). Why you only need to test with 5 users. *Nielsen Norman Group*. Retrieved from http://www.nngroup.com/articles/why-you-only-need-to-test-with-5-users/

Northcote, M. T., & Marshall, L. (2016). What mathematics calculations do adults do in their everyday lives? Part 1 of a report on the Everyday Mathematics project. *Australian Primary Mathematics Classroom, 21*(2), 8–17.

Núñez Castellar, E., Van Looy, J., Szmalec, A., & De Marez, L. (2014). Improving arithmetic skills through gameplay: Assessment of the effectiveness of an educational game in terms of cognitive and affective learning outcomes. *Information Sciences, 264*, 19–31.

Núñez-Peña, M. I., Guilera, G., & Suárez-Pellicioni, M. (2014). The single-item math anxiety scale: An alternative way of measuring mathematical anxiety. *Journal of Psychoeducational Assessment, 32*(4), 306–317.

OECD. (2012). *United Kingdom – Country Note – Results from PISA 2012*. OECD. Retrieved from http://www.oecd.org/unitedkingdom/PISA-2012-results-UK.pdf

OECD. (2024). *PISA 2022 results (Volume V): Learning strategies and attitudes for life*. OECD Publishing. https://doi.org/10.1787/c2e44201-en

Onebunne, J., & Onyinye, U. (2019). Students' perception of the factors responsible for declining interest in secondary school mathematics in Aguata Local Government Area of Anambra State. *Nnadiebube Journal of Education in Africa (NJEA), 3*(1), 87–105.

Owens, M., Stevenson, J., Hadwin, J. A., & Norgate, R. (2012). Anxiety and depression in academic performance: An exploration of the mediating factors of worry and working memory. *School Psychology International, 33*(4), 433–449.

Paechter, M., Macher, D., Martskvishvili, K., Wimmer, S., & Papousek, I. (2017). Mathematics anxiety and statistics anxiety: Shared but also unshared components and antagonistic contributions to performance in statistics. *Frontiers in Psychology, 8*, 1196.

Papadakis, S., & Kalogiannakis, M. (2017). Mobile educational applications for children: What educators and parents need to know. *International Journal of Mobile Learning and Organization, 11*(3), 256–277.

Petri, G., & von Wangenheim, C. G. (2016). How to evaluate educational games: A systematic literature review. *Journal of Universal Computer Science, 22*(7), 992–1021.

Petticrew, M., & Roberts, H. (2006). Why do we need systematic reviews? In *Systematic Reviews in the Social Sciences: A Practical Guide* (pp. 1–26).

Piccirilli, M., Lanfaloni, G. A., Buratta, L., Ciotti, B., Lepri, A., Azzarelli, C., Ilicini, S., D'Alessandro, P., & Elisei, S. (2023). Assessment of math anxiety as a potential tool to identify students at risk of poor acquisition of new math skills: Longitudinal study of grade 9 Italian students. *Frontiers in Psychology, 14*, 1185677.

Plaisance, D. (2009). A teacher's quick guide to understanding mathematics anxiety. *Louisiana Association of Teachers of Mathematics Journal, 6*(1), 1–8.

Plake, B. S., & Parker, C. S. (1982). The development and validation of a revised version of the mathematics anxiety rating scale. *Educational and Psychological Measurement, 42*(2), 551–557.

Plotegher, B., Wood, G., Moeller, K., Nuerk, H.-C., & Kerschbaum, H. H. (2010). Predictors of performance in a real-life statistics examination depend on the individual cortisol profile. *Biological Psychology, 85*(3), 410–416.

Pope, C., & Mays, N. (2020). The role of theory in qualitative research. In *Qualitative Research in Health Care* (pp. 15–26). Wiley.

Pötzsch, H., & Hammar, E. L. (2023). Digital games as media for teaching and learning: A template for critical evaluation. *Simulation & Gaming, 54*(3), 348–374.

Price, G. R., Holloway, I., Räsänen, P., Vesterinen, M., & Ansari, D. (2007). Impaired parietal magnitude processing in developmental dyscalculia. *Current Biology, 17*(24), R1042–R1043.

Prieto, G., & Delgado, A. R. (2007). Measuring math anxiety (in Spanish) with the Rasch rating scale model. *Journal of Applied Measurement, 8*(2), 149–158.

Primi, C., & Chiesi, F. (2018). The role of mathematics anxiety and statistics anxiety in learning statistics. In *Proceedings of the 10th International Conference on Teaching Statistics (ICOTS 10)*. [Proceedings PDF].

Purnamasari, A. (2023). A systematic literature review on the effect of math anxiety towards math performance and achievement. Acceleration: Multidisciplinary Research Journal, 1(4), 157–167.

Puteh, M., & Khalin, S. Z. (2016). Mathematics anxiety and its relationship with the achievement of secondary students in Malaysia. *International Journal of Social Science and Humanity, 6*(2), 119–119.

Qashoa, S. H. (2012). EFL test anxiety: Effects, sources and strategies for alleviating it. *International Journal of Liberal Arts and Social Science, 1*(2), 1–10.

Rada, E., & Lucietto, A. M. (2022). Math anxiety – A literature review on confounding factors. Journal of Research in Science, Mathematics and Technology Education, 5(2), 117–129.

Ramirez, G., Gunderson, E. A., Levine, S. C., & Beilock, S. L. (2013). Math anxiety, working memory, and math achievement in early elementary school. *Journal of Cognition and Development, 14*(2), 187–202.

Ramirez, G., Shaw, S. T., & Maloney, E. A. (2018). Math anxiety: Past research, promising interventions, and a new interpretation framework. Educational psychologist, 53(3), 145-164.

Reddy, Y. B. (2008). Detecting primary signals for efficient utilization of spectrum using Q-learning. *In Proceedings of the International Conference on Electrical, Electronics and Computer Engineering* (pp. 360–365). IEEE.

Reichlin, L., Mani, N., McArthur, K., Harris, A., Rajan, N., & Dacso, C. (2011). Assessing the acceptability and usability of an interactive serious game in aiding treatment decisions for patients with localized prostate cancer. *Journal of Medical Internet Research, 13*(1), e4.

Reigosa-Crespo, V., Valdés-Sosa, M., Butterworth, B., Estévez, N., Rodríguez, M., Santos, E., Torres, P., Suárez, R., & Lage, A. (2012). Basic numerical capacities and prevalence of developmental dyscalculia: The Havana Survey. *Developmental Psychology, 48*(1), 123–139.

Resnick, H., Viehe, J., & Segal, S. (1982). Is math anxiety a local phenomenon? A study of prevalence and dimensionality. *Journal of Counseling Psychology, 29*(1), 39–47.

Richardson, F. C., & Suinn, R. M. (1972). The Mathematics Anxiety Rating Scale: Psychometric data. *Journal of Counseling Psychology, 19*(6), 551–555.

Rossman, G. B., & Wilson, B. L. (1985). Numbers and words: Combining quantitative and qualitative methods in a single large-scale evaluation study. *Evaluation Review, 9*(5), 627–643.

Rossnan, S. (2006). *Overcoming math anxiety*. Mathitudes, 1*(1), 1–4.

Rounds, J. B., & Hendel, D. D. (1980). Measurement and dimensionality of mathematics anxiety. *Journal of Counseling Psychology, 27*(2), 138–142.

Rubinsten, O., & Tannock, R. (2010). Mathematics anxiety in children with developmental dyscalculia. *Behavioral and Brain Functions, 6*(1), 46.

Sakdiyah, S. H., Eltivia, N., & Afandi, A. (2022). Root cause analysis using fishbone diagram: Company management decision making. *Journal of Applied Business, Taxation and Economics Research, 1*(6), 566–576.

Sammallahti, E., Finell, J., Jonsson, B., & Korhonen, J. (2023). A meta-analysis of math anxiety interventions. Journal of Numerical Cognition, 9(2).

Sandman, R. S. (1980). The mathematics attitude inventory: Instrument and user's manual. *Journal for Research in Mathematics Education, 11*(2), 148–149.

Saridaki, M., Gouscos, D., & Meimaris, M. G. (2009). Digital games-based learning for students with intellectual disability. In D. Ifenthaler (Ed.), *Games-Based Learning: Advancements for Multi-Sensory Human Computer Interfaces* (pp. 304–325). IGI Global.

Sauvé, L., Renaud, L., Kaufman, D., Samson, D., Bluteau-Doré, V., Dumais, C., Bujold, P., Kazsap, M., & IsaBelle, C. (2005). Revue systématique de écrits (1998-2004) sur les fondements conceptuels du jeu, de la simulation et du jeu simulé. *Journal sur l'Intégration Sociale et la Technologie, 7*(3), 42–61.

Scarpello, G. (2007). Helping students get past math anxiety. *Techniques: Connecting Education and Careers, 82*(6), 34–35.

Schumacker, R. E., & Lomax, R. G. (2016). *A beginner's guide to structural equation modeling* (4th ed.). Routledge.

Schutz, A. (1967). *The phenomenology of the social world* (G. Walsh & F. Lehnert, Trans.). Northwestern University Press.

Shields, D. J. (2006). *Causes of math anxiety: The student perspective*. Indiana University of Pennsylvania.

Sievert, M., Albritton, R. L., Roper, P., & Clayton, N. (1988). Investigating computer anxiety in an academic library. *Information Technology and Libraries, 7*(3), 243–252.

Silva, D. L., Tadeo, M. C., Reyes, C. R., & Dadigan, R. M. (2006). Factors associated with non-performing Filipino students in mathematics: A vision of student's cognitive and behavior management. *Proceedings of the 2nd IMT-GT Regional Conference on Mathematics, Statistics and Applications*, 2–3 June, Penang.

Smith, M. R. (2004). *Math anxiety: Causes, effects, and preventative measures*. Roeper Review, 26*(3), 186–190.

Smith, T. F., & Capuzzi, G. (2019). Using a mindset intervention to reduce anxiety in the statistics classroom. *Psychology Learning & Teaching*. Advance online publication. https://doi.org/10.1177/1475725719836641

Sorvo, R., Koponen, T., Viholainen, H., Aro, T., Räikkönen, E., Peura, P., Dowker, A., & Aro, M. (2017). Math anxiety and its relationship with basic arithmetic skills among primary school children. *British Journal of Educational Psychology, 87*(3), 309–327.

Sparks, S. D. (2011). Researchers probe causes of math anxiety. *Education Week, 30*, 31.
Spicer, J. (2004). Resources to combat math anxiety. *Eisenhower National Clearinghouse Focus, 12*(12).

Spitzer, R. L., Kroenke, K., Williams, J. B., & Löwe, B. (2006). A brief measure for assessing generalized anxiety disorder: The GAD-7. *Archives of Internal Medicine, 166*(10), 1092–1097.

Stoet, G., Bailey, D. H., Moore, A. M., & Geary, D. C. (2016). Countries with higher levels of gender equality show larger national sex differences in mathematics anxiety and relatively lower parental mathematics valuation for girls. *PLOS ONE, 11*(4), e0153857.

Stranger-Johannessen, E. (2018). Exploring math achievement through gamified virtual reality. In *2018 European Conference on Technology Enhanced Learning* (pp. 613–616). Springer.

Suinn, R. M., & Winston, E. H. (2003). The mathematics anxiety rating scale, a brief version: Psychometric data. *Psychological Reports, 92*(1), 167–173.

Sun, Y., & Pyzdrowski, L. (2009). Using technology as a tool to reduce mathematics anxiety. *The Journal of Human Resource and Adult Learning, 5*(2), 38–44.

Suri, R., Lee, J. A., Manchanda, R. V., & Monroe, K. B. (2003). The effect of computer anxiety on price value trade-off in the online environment. *Psychology & Marketing, 20*(6), 515–536.

Sweidan, S. Z., & Darabkh, K. A. (2018). VREG: A Virtual Reality Educational Game with Arabic content using Android smartphone. *Journal of Software Engineering and Applications, 11*(4), 500–520.

Tague, N. R. (2005). *The quality toolbox* (2nd ed.). ASQ Quality Press.

Teclaw, R., Price, M. C., & Osatuke, K. (2012). Demographic question placement: Effect on item response rates and means of a veterans health administration survey. *Journal of Business and Psychology, 27*(3), 281–290.

Tella, A. (2019). Globalized mathematics curriculum: Could it ever be possible? In *Globalized Curriculum Methods for Modern Mathematics Education* (pp. 38–55). IGI Global.

Tene, T., Vique López, D. F., Valverde Aguirre, P. E., Cabezas Oviedo, N. I., Vacacela Gomez, C., & Bellucci, S. (2025). *A systematic review of serious games as tools for STEM education.* Frontiers in Education, 10, 1432982.

The British Dyslexia Association. (2019). *Neurodiversity and co-occurring differences: Dyscalculia and maths difficulties*. Retrieved from https://www.bdadyslexia.org.uk/dyslexia/neurodiversity-and-co-occurring-differences/dyscalculia-and-maths-difficulties

Thornhill, A., Saunders, M., & Lewis, P. (2009). *Research methods for business students* (5th ed.). Prentice Hall.

Tobias, S. (1993). *Overcoming math anxiety*. W. W. Norton & Company.

Tobias, S., Fletcher, J. D., & Wind, A. P. (2014). Game-based learning. In J. M. Spector et al. (Eds.), *Handbook of research on educational communications and technology* (pp. 485–503). Springer.

Tokmak, H. S., Incikabi, L., & Ozgelen, S. (2013). An investigation of change in mathematics, science, and literacy education pre-service teachers' TPACK. *Asia-Pacific Education Researcher, 22*(4), 407–415.

Tobiipro.com. (2020). Design a usability test with eye tracking on mobile devices. Retrieved July 19, 2020, from https://www.tobiipro.com/learn-and-support/learn/steps-in-an-eye-tracking-study/design/designing-a-mobile-device-or-tablet-study/

Uldas, İ. (2005). Development of a mathematics anxiety scale towards teachers and teacher candidates (MAS-T) and an assessment on mathematics anxiety [Unpublished master's thesis]. Marmara University, Turkey.

UOS. (2020). *Institutional and Department student profiles*. Retrieved from https://apex-live.shef.ac.uk/pls/apex/f?p=136:1

University of Nottingham. (n.d.). *Two traditional research paradigms*. In *Understanding Pragmatic Research*. https://www.nottingham.ac.uk/helmopen/rlos/research-evidence-based-practice/designing-research/types-of-study/understanding-pragmatic-research/section02.html

University of Sussex. (2025, May). 'Maths anxiety' causes students to disengage. *Press release.* Retrieved from: https://www.sussex.ac.uk/broadcast/read/62664

Usop, H. H., Sam, H. K., Sabri, N. A., & Wah, T. K. (2009). Factors causing mathematics anxiety among undergraduate students. *Jurnal Teknologi, 50*(A), 17–22.

Van Eck, R. (2006). Digital game-based learning: It's not just the digital natives who are restless. *EDUCAUSE Review, 41*(2), 16–30.

Wang, Z., Hart, S. A., Kovas, Y., Lukowski, S., Soden, B., Thompson, L. A., Plomin, R., McLoughlin, G., Bartlett, C. W., & Lyons, I. M. (2014). Who is afraid of math? Two sources of genetic variance for mathematical anxiety. *Journal of Child Psychology and Psychiatry, 55*(9), 1056–1064.

Wouters, P., & Van Oostendorp, H. (2016). Overview of instructional techniques to facilitate learning and motivation of serious games. In Instructional techniques to facilitate learning and motivation of serious games (pp. 1-16). Cham: Springer International Publishing.

Vasanth, K., & Sbert, J. (2016). Creating solutions for health through technology innovation. *Texas Instruments White Papers*. Retrieved from http://www.ti.com/lit/wp/sszy006/sszy006.pdf

Venter, M., & de Wet, L. (2016). Continuance use intention of primary school learners towards mobile mathematical applications. In *2016 IEEE Frontiers in Education Conference (FIE)* (pp. 1–9). IEEE.

Verkjika, S. F., & De Wet, L. (2015). Using a brain–computer interface (BCI) in reducing math anxiety: Evidence from South Africa. *Computers & Education, 81*, 113–122.

Virvou, M., & Papadimitriou, S. (2003). A browser-based educational game with adaptivity. *International Journal of Computers for Mathematical Learning, 8*(2), 127–138.

Virvou, M., & Papadimitriou, S. (2013). Simple arithmetic lessons through an adaptive snake game. In *Proceedings of the 2013 International Conference on Computer, Information and Telecommunication Systems (CITS)* (pp. 1–4). IEEE.

Whitton, N. (2007). Motivation and computer game-based learning. In *Proceedings of the 24th Annual Conference of the Australian Society for Computers in Learning in Tertiary Education (ASCILITE 2007)* (pp. 1063–1067).

Wiederhold, B. K., & Bouchard, S. (2014). *Advances in virtual reality and anxiety disorders*. Springer.

Wigfield, A., & Eccles, J. S. (2000). Expectancy–value theory of achievement motivation. *Contemporary Educational Psychology, 25*(1), 68–81.

Wigfield, A., & Meece, J. L. (1988). Math anxiety in elementary and secondary school students. *Journal of Educational Psychology, 80*(2), 210–216.

Woodard, T. (2004). The effects of math anxiety on post-secondary developmental students as related to achievement, gender, and age. *Inquiry, 9*(1), n1.

Yahya, F. A., Adullasim, N., & Ahmad, I. (2019). The evaluation of mobile educational game design using 3i factors. In *2019 IEEE 9th International Conference on System Engineering and Technology (ICSET)* (pp. 227–231). IEEE.

Yavuz, G. (2018). Mathematics anxiety of ninth grade students. *Journal of Education and Training Studies, 6*(5), 21–27.

Young, M. F., Slota, S., Cutter, A. B., Jalette, G., Mullin, G., Lai, B., Simeoni, Z., Tran, M., & Yukhymenko, M. (2012). *Our princess is in another castle: A review of trends in serious gaming for education*. Review of Educational Research, 82(1), 61–89.

Yu, R. (2015). Choking under pressure: The neuropsychological mechanisms of incentive-induced performance decrements. *Frontiers in Behavioral Neuroscience, 9*, 8.

Zagal, J. P., Rick, J., & Hsi, I. (2006). Collaborative games: Lessons learned from board games. *Simulation & Gaming, 37*(1), 24–40.

Zakaria, E., & Nordin, N. M. (2008). The effects of mathematics anxiety on matriculation students as related to motivation and achievement. *Eurasia Journal of Mathematics, Science & Technology Education, 4*(1), 27–30.

Zeidmane, A., & Rubina, T. (2017). Student-related factor for dropping out in the first year of studies at LLU engineering programmes. *Engineering for Rural Development, 16*, 612–618.

Zerbolio Jr, D. J. (1989). A “bag of tricks” for teaching about sampling distributions. *Teaching of Psychology, 16*(4), 207–209.

Zhang, Y., Sun, S., Han, Z., & Tang, M. (2019). Research on the cultivation of interest in learning mathematics under the background of Internet Plus. In *3rd International Seminar on Education Innovation and Economic Management (SEIEM 2018)*.

Appendices

Appendix A

Figures

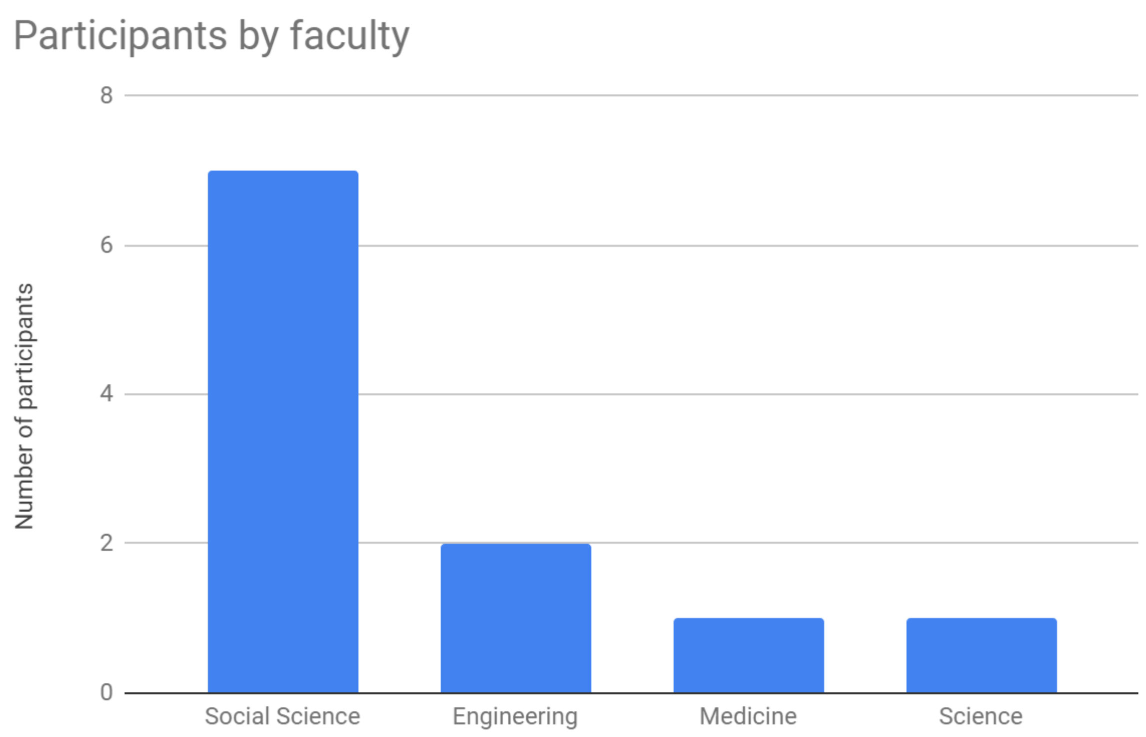

Figure 15: Participants by faculty

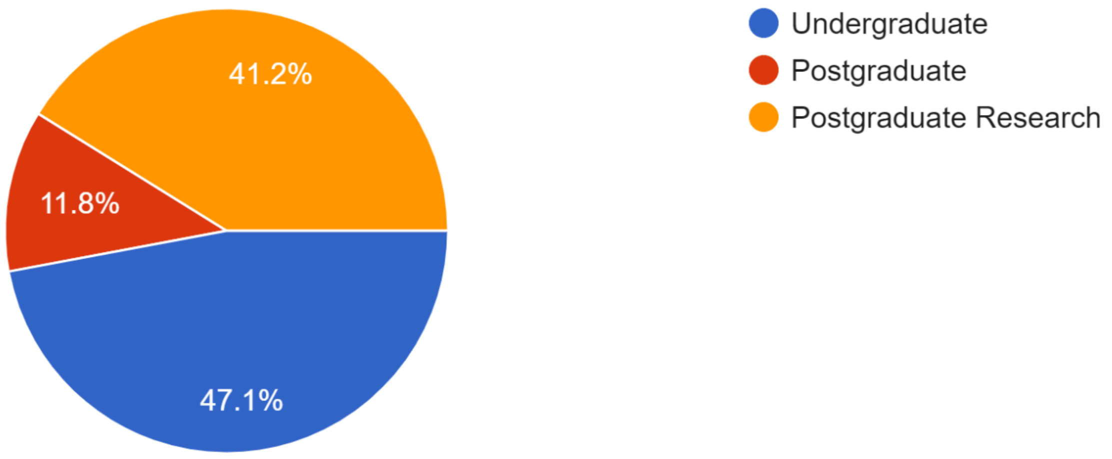

Figure 16: Degree level of participants

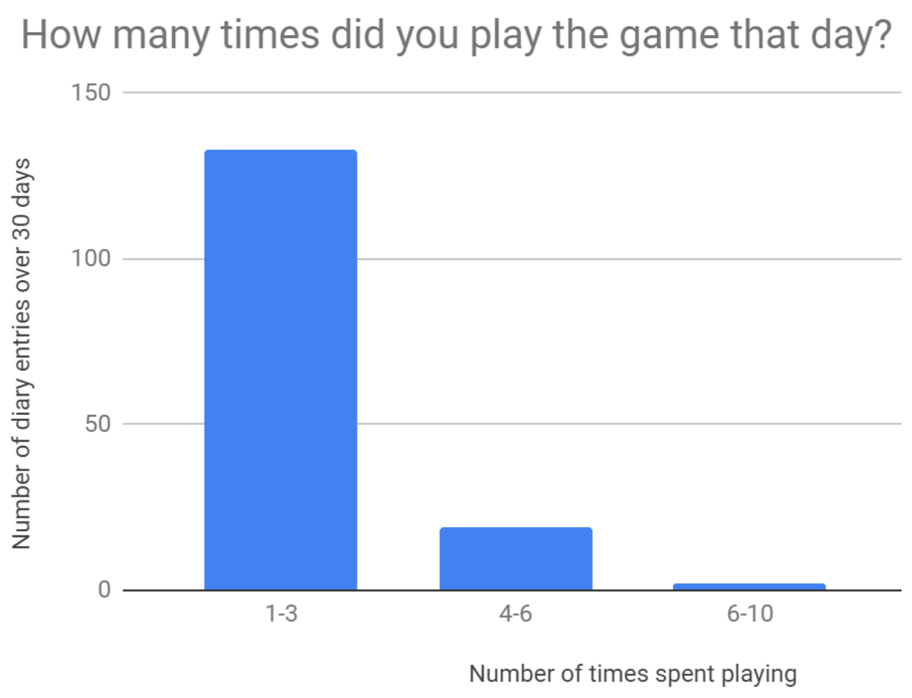

Figure 17: Duration of play time

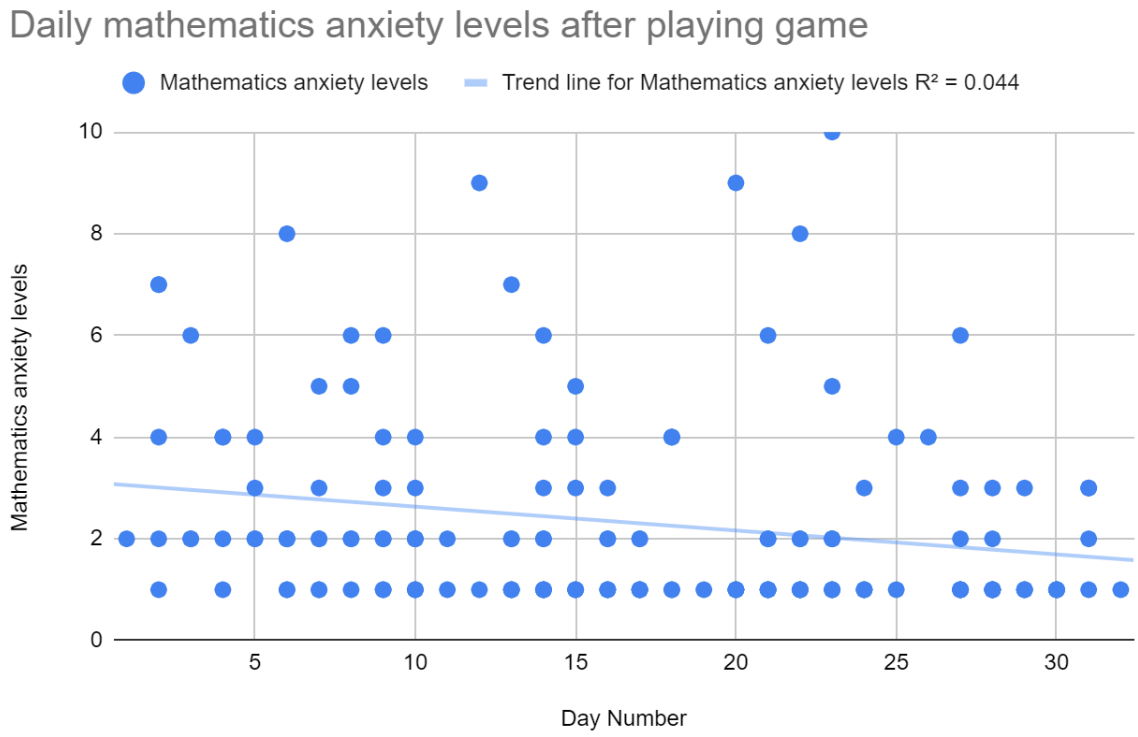

Figure 18: Daily mathematics anxiety after playing the game

Appendix B

Tables

Table 14 - Participant 20 profile (no change in mathematics anxiety)

Pre-game mathematics anxiety Score	66
Post-game mathematics anxiety Score	66
Gender	Male
Age	25-34
Nationality	Chinese
Study level:	PhD
Subject Area:	Information Studies
Last mathematics qualification	No qualification (standard Chinese senior high school education)
Last mathematics qualification completed	6 years ago
Computer games playing frequency	Occasionally
Played Bubble Function before?	No

Table 15: Participant 6 profile (steep drop in mathematics anxiety)

Pre-game mathematics anxiety Score	123
Post-game mathematics anxiety Score	69
Gender	Female
Age	25-34
Nationality	Mexican
Study level:	Postgraduate research
Subject Area:	Information studies

Last mathematics qualification	Bachelor’s degree
Last mathematics qualification completed	6+ years ago.
Computer games playing frequency	Never
Played Bubble Function before?	No

Table 16 Participants 00002 profile (increase in mathematics anxiety)

Pre-game mathematics anxiety Score	46
Post-game mathematics anxiety Score	49
Gender	Male
Age	25-34
Nationality	Serbian
Study level:	Post-doctoral researcher
Subject Area:	Information studies
Last mathematics qualification	High school mathematics
Last mathematics qualification completed	6+ years ago
Computer games playing frequency	Daily
Played Bubble Function before?	No

Appendix C

Study 1 ethics approval letter

The University Of Sheffield.

Application 003413

Section A: Applicant details

Created:
Wed 25 March 2015 at 13:41

First name:
Marc

Last name:
Bonne

Email:
mabonne1@sheffield.ac.uk

Programme name:
INFR41

Module name:
INFR41
Last updated:
12/06/2015

Department:
Information School

Date application started:
Wed 25 March 2015 at 13:41

Applying as:
Postgraduate research

Research project title:
Educational computer games and their impact on maths anxiety in University students

Section B: Basic information

1. Supervisor(s)

Name	Email
Sheila Webber	s.webber@sheffield.ac.uk

2: Proposed project duration

Proposed start date:
Thu 7 May 2015

Proposed end date:
Fri 8 May 2015

3: URMS number (where applicable)

URMS number
- not entered -

4: Suitability

Takes place outside UK?
No

Involves NHS?
No

Healthcare research?
No

ESRC funded?
No

Involves adults who lack the capacity to consent?
No

Led by another UK institution?
No

Involves human tissue?
No

Clinical trial?
No

Social care research?
No

5: Vulnerabilities

Involves potentially vulnerable participants?
No
Involves potentially highly sensitive topics?
No

Section C: Summary of research

1. Aims & Objectives

The aim of this pre-pilot study project is to identify any issues or constraints in using certain educational computer games for the pilot and main study of the research. The main study aims to investigate the extent to which educational maths based computer games impact on maths anxiety in University students. Several games have been identified that could be used for the study, however each game consists of a variety of user experiences (e.g. time to answer questions, graphics, sound, reward systems, complexity of the interfaces and completion time). Additionally, each game belong's to different websites that may vary in terms of speed or availability of content. Therefore, it is important to test each game to find which game participants find the most convenient to play-through so that game can be used for the pilot and main study.

2. Methodology

This pre-pilot consists of a qualitative observation (think aloud) task and an interview. Five students will be selected from the University of Sheffield's Information School as they are all social science students. Each participant will be given the 3 selected games to play for the study (each one taking around 10 minutes to complete. The process will take place in the Information School's iLab, where the participants facial reactions and speech will be recorded. Any mouse and keyboard strokes will also be recorded using the iLab's Morae software available. Participants will be asked to "think-aloud" as they are playing through each game.

After each game, participants will then be interviewed on their experience playing each game. The interview will take approximately 10 minutes. Participants may have the audio from the think-aloud study played back to them for clarification purposes. All data will be stored on the University's servers to be coded in order to identity any trends and themes in the user experienced data.

3. Personal Safety

Raises personal safety issues? No

Pesonal safety management

- not entered -

Section D: About the participants

1. Potential Participants

The five participants will be students from the University of Sheffield's Information School as they are not only social science students, but in using the convenient sampling approach for this pre-pilot study, are also of convenient accessibility and proximity to the researcher. These can be PhD, masters or undergraduate students.

2. Recruiting Potential Participants

Potential participants will be contacted via email to take part in the study. The information in the email will contain a description of the purpose of the study, description of the participant needed, what the participant will be doing in the study. Furthermore, it will include the study process, the date and times for when any data collection will be taking place, along with the location.

2.1 Advertising methods

Will the study be advertised using the volunteer lists for staff or students maintained by CiCS? No

- not entered -

3. Consent

Will informed consent be obtained from the participants? (i.e. the proposed process) Yes

When the participants arrives to the Information School's iLab, they will be given a paper-based consent form to sign. The consent form will contain information about the purpose of the research, what the participant will be doing, the data to be collected from the participant as well as how their data will be stored and processed. The participant can sign the form in writing.

4. Payment

Will financial/in kind payments be offered to participants? No

- not entered -

5. Potential Harm to Participants

What is the potential for physical and/or psychological harm/distress to the participants?

Participants will not be exposed to risks that are greater than, or additional to, those they encounter in their normal lifestyles.

How will this be managed to ensure appropriate protection and well-being of the participants?

Both the think aloud task, as well as any interview or demographic questions are designed as not to cause harm, anguish or discomfort. If participants feel uncomfortable answering any of the questions, or taking part in any part of the think aloud study, they are free to express their concerns, decline to take part in such activities, or withdraw from participation completely at any time by asking to do so. Participants are moreover encouraged to refrain from disclosing any information that they may consider defamatory, incriminating, or otherwise sensitive. Participants will also be assigned a number to be used in place of their names when analyzing the data in order to conceal their identity.

Section E: About the data

1. Data Confidentiality Measures

To ensure anonymity, participants will be assigned a participant number (e.g. Participant 1) which will be used throughout the analysis of the data. No identifying information will be retained.

2. Data Storage

The think-aloud video or audio data will be stored on the University of Sheffieldâ€™s secure servers. The questionnaire data and handwritten notes from the interview will be stored in a locker in the Information School lab. Audio data for the interview will also be stored on the Universityâ€™s servers. The data will be analyzed for inclusion in the pilot study section of the thesis. Any data will be accessible to the researcher and research team.

Section F: Supporting documentation

Information & Consent

Participant information sheets relevant to project?
Yes

Participant Information Sheets

- ResearchInformationSheet.docx
  (Document 007422)
- Research_Ethics_-_Information_Sheet.docx
  (Document 007745)
- Research_Ethics_-_Information_Sheet.docx
  (Document 007741)
- Research_Ethics_-_Information_Sheet.docx
  (Document 007761)

Consent forms relevant to project?
Yes

Consent Forms

- Consent-Form.doc
  (Document 007604)

Additional Documentation

- Demographic_Questionnaire.docx (Document 007765)
  Demographic questionnaire given to participants prior to usability study.

External Documentation

- not entered -

Offical notes

- not entered -

Section G: Declaration

Signed by:
Marc Bonne
Date signed:
Fri 1 May 2015 at 16:59

Appendix D

Proposed interview questions (Study 4)

1. Which part of the game made you feel the most anxious?

2. Which part of the game made you feel the most confident?

3. [Show participant their mathematics anxiety score/percentile] What do you think of mathematics anxiety score before the game? Is it an accurate reflection on how you feel about mathematics?

4. How has the game affected your mathematics anxiety levels overall? (note: Mathematics anxiety is defined as "*a feeling of tension, apprehension, or fear that interferes with math performance"* (Ashcroft, 2002)? – *circle as appropriate*

Very Confident					No difference at all					Very Anxious
5	4	3	2	1	0	1	2	3	4	5

Other comments

5. Do you have any other comments about your experience playing the game?

Appendix E

Section 1: Interview codes and themes

Name (themes identified highlighted in bold)	**Sources** *(number of areas where the code occurred)*	**References** *(number of times the code occurred)*
Anxiety	14	49
Increased anxiety	11	21
Anxiety caused by feedback	1	1
Anxiety caused by getting wrong answers	3	5
Rushing through the game	2	2
Anxiety caused by harder difficulty	5	5
Anxiety caused by complex questions	1	1
Anxiety caused by task overload	1	1
Anxiety caused by time limit	1	2
Anxiety caused by interface	1	1
Anxiety caused by problem solving	1	2
Anxiety caused by real world application	2	5
Anxiety caused by reward system	1	1
Anxiety caused by negative feedback	1	1
Anxiety caused by structure	1	1
Fear of starting all over again	1	1
Maths Anxiety	13	24
Decrease in maths anxiety	5	6
Decreased because it's a game	1	2
Decreased because of maths subject	1	1
Increased maths anxiety	4	6
Maths anxiety affected by topic	1	1
Maths anxiety hinders performance	1	1
Small increase in maths anxiety	3	4
Need to be more careful	1	1
No affect on maths anxiety	5	10
Game was not fun	1	1

However topic was harder	1	1
Maths topic prevented maths anxiety	1	1
No storyline	1	1
Refreshed memory	2	2
No anxiety	3	4
Choice of difficulty	1	1
Atmosphere	3	4
Alternative to classroom environment	1	1
Calming	2	2
Game is relaxing	1	1
No pressure	1	1
No atmosphere	1	1
Characters	7	11
Characters are relatable	1	1
Characters are stereotypes	1	2
Characters not a good fit	1	1
Characters were a good fit	1	1
Characters were not relatable	2	3
Characters different to target audience	1	2
Characters were threatening	1	1
Lack of characters	2	2
No characters at all	0	0
Confidence	14	38
Increased confidence	14	35
Confidence caused by atmosphere	1	1
Confidence caused by controls	1	1
Confidence caused by easy challenges	5	10
Confidence caused by no timer	1	3
Confidence caused by easy questions	1	1
Confidence caused by feedback system	2	2
Confidence caused by increased understanding	2	2
Confidence caused by observable improvement	3	5
Confidence caused by correct answers	3	4

Confidence from improving speed	1	1
Confidence caused by sound	1	1
Confidence caused by the user interface	1	1
Confidence caused diffculty perception	1	1
Confidence from clear difficulty levels	1	2
Confidence in maths subject	1	1
No changes in confidence	1	1
Engagement	13	17
Eager to play again	5	6
Game is engaging	1	1
Engaging because it's relaxing	1	1
Engaging because it's tense	1	1
Unengaging	6	9
Unless you want to learn the subject	1	1
Will only play for training purposes	1	1
Will only play once	1	1
Won't play again if performing well	1	1
Won't play for long	1	1
Fun	14	27
Fun is dependent on the player	1	2
Game is fun	7	10
Fun because game is target driven	1	1
Fun because of reward system	1	1
Forgiving reward system	1	1
Fun because of slow pace	2	2
Fun because of topic	1	1
Fun because player has responsibilities.	1	1
Fun but logical	1	2
Fun for what it is	1	1
Makes learning fun	1	1
Fun when performing well	1	1
Not fun	6	13
Don't want to start again	1	1

Fun as a training game	2	2
Maths was too simple	1	1
Needs more story	1	2
Overly Repetitive	1	1
Tedious	1	1
Game Progression	15	22
Difficulty progression	13	18
Clear progression	13	17
Difficulty levels felt different	1	1
Difficulty levels feel the same	1	1
Difficulty was easy throughout	2	4
Maths tasks lack variety	2	9
Screen progression	3	4
Easy transitioning through screens	1	1
Game was too fast	1	1
No help needed	1	1
Progression was confusing	1	1
Requires experimentation first	1	1
Gameplay	14	28
Controls	14	23
Controls are clearly explained	1	1
Difficult controls	5	9
Controls require practice	2	2
Unintuitive Controls	3	5
Easy controls	9	11
Easy once understood	1	1
Easy to learn	4	5
Gameplay is a good fit	1	1
Gameplay is boring	2	2
Gameplay is easy to understand	1	1
Simple gameplay	1	1
Instructions	10	19
Game did not need instructions	4	5

Controls understood without instructions	1	1
Instructions shown throughout the game	1	1
Structure understood without instructions	1	1
Instructions are clear	6	7
Instructions are helpful	1	1
Should have read instructions first	1	2
Instructions unclear	3	4
Instructions clear after playing game	2	2
Wall of text	1	1
Learnability	5	5
Learnable for beginners in the topic	1	1
Learnable for casual gamers	3	3
Learnable for non-maths people	1	1
Learning	4	6
Did not learn anything	2	2
Makes use of existing skills	1	1
Not much to learn	1	1
Skill improvement	1	2
Faster thinking	1	1
Good for mental maths	1	1
Motivation	3	6
Motivated by failure	2	2
Motivated by success	1	1
Unmotivational	1	2
Readability	15	27
Good readability	15	27
Good font contrast	2	2
Good with glasses on	1	1
Just plain text	1	2
Legible font size	11	12
Simple sentence structure	2	2
Real world application	4	12
Feels like a training game	2	3

Reward	3	3
Confusing reward system	1	1
Reward system is clear	1	1
Sound	1	1
No sound	1	1
Storyline	13	42
Didn't pay attention to storyline	1	2
Storyline is skippable	1	1
Easy to follow storyline	3	3
Generally good storyline	1	1
Lack of story	5	12
Conceptual game	1	2
Feels more like a tutorial	1	1
Feels more like an exam	1	1
No story at all	4	6
Simple storyline	1	3
Storyline is a good fit	2	4
Storyline is boring	1	1
Storyline is relatable	2	6
Storyline brought back memories	1	1
Storyline was non-threatening	1	2
Storyline is understood	5	6
Storyline is unrelatable	1	1
Storyline is threatening	1	1
Storyline not a good fit	2	2
Structure	14	48
Clear Structure	7	8
Easy to understand	1	1
No help needed	3	3
Game Objectives	13	18
Bland objectives	1	1
Clear objectives	13	17
Clear after some playthrough	0	0

Objectives are simple	1	1
Unclear objectives	0	0
Questions were clear, but not story	1	1
Initially Confusing Structure	5	5
Need more time to play	1	1
Should have studied structure first	1	2
Structure changes made it more difficult.	1	1
Logical structure	1	1
Simple structure	7	10
Game levels are small	2	2
Uninteresting structure	2	5
Repetitive Structure	1	2
Target audience	7	12
Adult audience	1	3
No story needed	1	1
Could waste their time	1	1
Unless they find maths boring	1	1
Would confuse user	0	0
Child audience	5	7
Kids need story	1	1
Employee audience	2	2
User Interface	13	39
Boring interface	2	3
Easy user interface	8	15
Buttons are clear	1	2
Feedback is clear	5	7
Explicit graphics	2	2
Good graphics	1	1
Logical user interface	1	2
Simple graphics	5	6
Unclear interface	2	3
Buttons are unclear	1	1
Uninteresting graphics	3	7

Themes

- Anxiety
- Atmosphere
- Characters
- Confidence
- Engagement
- Fun
- Game Progression
- Gameplay
- Instructions
- Learnability
- Learning
- Motivation
- Readability
- Real world application
- Reward
- Sound
- Storyline
- Structure
- Target audience
- User Interface

Global themes

Combining the general themes identified above the Study 1 codes, three global themes developed below. These themes are Game Usability Factors, Game User Experience Factors, and Learning Experience Factors. Both game usability and user experience are based on the ISO definitions. Usability is defined as *"effectiveness, efficiency and satisfaction with which specified users achieve specified goals in particular environments"*(International Organization for Standardization, 1998). In this case, the goal for participants was to, complete as many of the objectives of the game as possible within the 10-minute recording session. Effectiveness would refer to the how much of the game has completed. Efficiency refers to the time spent completing the objectives in the game User experience is defined as *"all aspects of the user's experience when interacting with the product, service, environment or facility"* (International Organization for Standardization, 1998). Based on these definitions, readability

Game usability factors	**Game user experience factors**	**Learning experience factors**

Readability	Reward	Learnability
Structure	Storyline	Learning
User interface	Engagement	Instructions
Sound	Fun	Game progression (difficulty)
Gameplay	Atmosphere	Real world application
Game progression (screen)	Characters	
	Motivation	
	Confidence	
	Anxiety	

Section 2: Observation template (Study 1)

The template below illustrates the structure used to record participant behaviour, affective responses, and gameplay performance during Study 1 observations. Original field notes were summarised in NVivo and coded using the framework above. Although the exact observation sheets were not preserved, this template accurately represents the fields and categories used to collect the data.

Field	Description	Example Entry
Participant ID	Unique code for participant	P04
Game Title	Name of game played	*Giving Change*

Session Duration (mins)	Recording length	10
Overall Behaviour Summary	Short description of participant's visible behaviour and comments	"Appears anxious during initial tasks; pauses frequently; smiles after correct answers."
Anxiety Indicators	Facial expression, gaze, or verbal signs of anxiety	"Rapid blinking, frowning, sighing after mistakes."
Confidence Indicators	Verbal statements or body language showing confidence	"Says 'this one's easy'; sits forward."
Engagement Indicators	Physical posture, attention, reactivity	"Leans closer to screen; laughs when receiving positive feedback."
Gameplay / Usability Notes	Interface issues, pacing, controls	"Confused by button layout at start; adjusted after 2 minutes."
Learning Indicators	Signs of conceptual understanding or skill improvement	"Solves similar tasks faster in second half; explains reasoning aloud."
Emotional Triggers	Notable events causing emotional reaction	"Frowns when game resets; relief after finishing last question."
Post-Game Comments	Participant reflections during debrief	"Says maths part was easy but time limit was stressful."

Coded Themes (applied later)	Relevant themes from framework	Anxiety → "Anxiety caused by feedback"; Confidence → "Increased confidence"

Appendix F

Study 1 Demographic questionnaire

What is your name?

____

What is your age range?

18-24 years old

25-34 years old

35-44 years old

45-54 years old

55 or older

What is your gender?

- [ ] Female
- [ ] Male
- [ ] Trans*
- [ ] ______________________________(fill in the blank)

What is your first language?

____

How would you describe your nationality?

____

What level are you currently studying at?

- Undergraduate
- Postgraduate Taught
- Postgraduate Research

What course are you currently studying?

____

What is the highest level of mathematics education you have completed to date?

________________________ (e.g. GCSE, A-Level, undergraduate level, other qualification)

How often do you play computer games?

(circle as appropriate)

Daily   Weekly   Monthly   Occasionally   Never

Have you played any of the following games before?

(circle as appropriate)

Algebra Meltdown – MangaHigh

Ordering Fractions – BBC Skillwise

Giving Change Game (no timer)- BBC Skillwise

None of the above

Appendix G

Study 3 and 4 demographic questionnaire

What is your name?

____

What is your age range?

- 18-24 years old
- 25-34 years old
- 35-44 years old
- 45-54 years old
- 55 or older

What is your gender?

- [ ] Female
- [ ] Male
- [ ] Trans*
- [ ] ______________________________(fill in the blank)

What is your first language?

____

What is your nationality?

____

What level are you currently studying at?

Undergraduate

Postgraduate Taught

Postgraduate Research

What course are you currently studying?

____ (e.g. BSc Psychology, BA Economics).

What is the highest level of mathematics education you have completed to date?

________________________ (e.g. GCSE, A-Level, undergraduate level, other qualification)

When did you finish this qualification?

(circle as appropriate)

0 – 1 year ago   1 to 2 years ago   2 to 3 years ago   3 to 4 years ago   5+ years ago

How often do you play computer games?

(circle as appropriate)

Daily   Weekly   Monthly   Occasionally   Never

Have you played any of the following games before?

(circle as appropriate)

Algebra Meltdown – MangaHigh   **Giving Change Game (no timer)** - BBC Skillwise

Appendix H

Everyday mathematics demographics and questionnaire

About you

2. **1) What is your age?** *
Mark only one oval.

- ◯ 18-24
- ◯ 25-34
- ◯ 35-44
- ◯ 45-54
- ◯ 55 or older

3. **2) Are you a:** *
Mark only one oval.

- ◯ UK/EU student? *After the last question in this section, skip to question 7.*
- ◯ Overseas student?

4. **3) Which department are you enrolled in?** *
Mark only one oval.

- ◯ School of Architecture
- ◯ School of East Asian Studies
- ◯ Department of Economics
- ◯ School of Education
- ◯ Department of Geography
- ◯ Information School
- ◯ Department of Journalism Studies
- ◯ Department of Landscape
- ◯ School of Law
- ◯ Management School
- ◯ Department of Politics
- ◯ Department of Sociological Studies
- ◯ Department of Urban Studies and Planning
- ◯ Sheffield Methods Institute

5. 4) What nationality are you? *

Mark only one oval.

- Other
- Afghan
- Albanian
- Algerian
- American
- Andorran
- Angolan
- Antiguans
- Argentinean
- Armenian
- Australian
- Austrian
- Azerbaijani
- Bahamian
- Bahraini
- Bangladeshi
- Barbadian
- Barbudans
- Batswana
- Belarusian
- Belgian
- Belizean
- Beninese
- Bhutanese
- Bolivian
- Bosnian
- Brazilian
- British
- Bruneian
- Bulgarian
- Burkinabe
- Burmese
- Burundian
- Cambodian
- Cameroonian
- Canadian
- Cape Verdean
- Central African
- Chadian
- Chilean
- Chinese

- Ukrainian
- Uruguayan
- Uzbekistani
- Venezuelan
- Vietnamese
- Welsh
- Welsh
- Yemenite
- Zambian
- Zimbabwean

6. **If other, please specify below**

____

Accommodation

7. **5) Are you staying in student accommodation?**
Mark only one oval.

- Yes. I'm living in student halls.
- Yes, I'm living in a house / flat share.
- No, I'm living at home.

Mathematics in everyday life

8. **6) Think about the last time you used mathematics outside of your course or job (e.g. shopping, travelling, playing sport, cooking, planning parties or any other examples). Write about this experience below:** *

____
____
____
____
____

Appendix I -

Mathematics anxiety rating scale: short version (MARS-SV)

The items in the questionnaire refer to things that may cause fear or apprehension. For each item decide which of the ratings best describes how much you are frightened by it nowadays - “Not at all” “A little” “A fair amount” “Much” or “Very much”. Mark your answers on the answer sheet only. On the answer sheet, fill in “1” for Not at all; “2” for A little, “3” for A fair amount, “4” for Much or “5” for Very much.

Do not mark this question sheet. Work quickly but be sure to consider each item individually.

	Not at all	A littl e	A fair amoun t	Muc h	Very muc h
1. Taking an examination (final) in a math course.					
2. Thinking about an upcoming math test one week before.					
3. Thinking about an upcoming math test one day before.					
4. Thinking about an upcoming math test one hour before.					
5. Thinking about an upcoming math test five minutes before.					
6. Waiting to get a math test returned in which you expected to do well.					

7. Receiving your final math grade in the mail.					
8. Realizing that you have to take a certain number of math classes to fulfill the requirements in your major.					
9. Being given a “pop” quiz in a math class.					
10. Studying for a math test.					
11. Taking the math section of a college entrance exam.					
12. Taking an examination (quiz) in a math course.					
13. Picking up the math text book to begin working on a homework assignment.					
14. Being given a homework assignment of many difficult problems which is due the next class meeting.					
15. Getting ready to study for a math test.					
16. Dividing a five digit number by a two digit number in private with pencil and paper.					
17. Adding up 976 + 777 on paper.					

18. Reading a cash register receipt after your purchase.					
19. Figuring the sales tax on a purchase that costs more than $1.00.					
20. Figuring out your monthly budget.					
21. Being given a set of numerical problems involving addition to solve on paper.					
22. Having someone watch you as you total up a column of figures.					
23. Totaling up a dinner bill that you think overcharged you.					
24. Being responsible for collecting dues for an organization and keeping track of the amount.					
25. Studying for a driver's license test and memorizing the figure involved, such as the distance it takes to stop a car going at different speeds.					
26. Totaling up the dues received and the expenses of a club you belong to.					
27. Watching someone work with a calculator.					
28. Being given a set of division problems to solve.					

29. Being given a set of subtraction problems to solve.					
30. Being given a set of multiplication problems to solve. 					

Appendix J

Diary study form

Section 1 of 4

Bubble Function Diary Study

Enter the details of your gaming experience here.

Email*

Valid email address

This form is collecting email addresses.Change settings

Which date did you play the game?

What time did you play the game?

How many times did you play the game that day?

*

1.

2.

3.

4.

5.

How did you feel about the game that day?

Not Anxious

1

2

3

4

5

6

7

8

9

10

Very Anxious

After section 1

Continue to next section

Section 2 of 4

General anxiety

Description (optional)

How anxious did you feel that day overall?

Not anxious

1

2

3

4

5

6

7

8

9

10

Very anxious

Please explain why

Long-answer text

Did you do any mathematics outside of the game that day?

Section 3 of 4

Everyday mathematics

Description (optional)

Think about the last time you used mathematics that day, choose an activity you did below:

1.

2.

3.

4.

5.

6.

7.

8.

9.

10.

11.

12.

13.

14.

15.

16.

17.

18.

19.

20.

21.

22.

23.

24.

25.

26.

What mathematics topic did you cover?

Other…

On a scale of 1 to 5, how anxious did you feel doing mathematics in this scenario?

Not anxious

1

2

3

4

5

Very anxious

Why do you think you felt the anxious carrying out this task?

Other…

After section 3

Continue to next section

Section 4 of 4

Mathematics anxiety

Description (optional)

Briefly describe how you solved the maths problems in the game?

*

Other…

On a scale from 1 to 10, how anxious are you about mathematics after playing the game today?

*

Not anxious

1

2

3

4

5

6

7

8

9

10

Very anxious

Which part of the game made you feel most anxious

Long-answer text

Which part of the game made you feel most confident?

Long-answer text

Any other comments about the game or the study in general?

Long-answer text

Appendix K

MATHEMATICS ANXIETY RATING SCALE: SHORT VERSION (MARS-SV) – UK

The items in the questionnaire refer to things that may cause fear or apprehension. For each item decide which of the ratings best describes how much you are frightened by it nowadays - "Not at all" "A little" "A fair amount" "Much" or "Very much". Mark your answers on the answer sheet only. On the answer sheet, fill in "1" for Not at all; "2" for A little, "3" for A fair amount, "4" for Much or "5" for Very much.
Do not mark this question sheet. Work quickly but be sure to consider each item individually.

	Not at all	A little	A fair amount	Much	Very much
1. Taking an examination (final) in a maths course.					
2. Thinking about an upcoming maths test one week before.					
3. Thinking about an upcoming maths test one day before.					
4. Thinking about an upcoming maths test one hour before.					
5. Thinking about an upcoming maths test five minutes before.					
6. Waiting to get a maths test returned in which you expected to do well.					
7. Receiving your final maths grade in the mail.					
8. Realizing that you have to take a certain number of maths modules to fulfil the requirements in your course.					
9. Being given a surprise quiz in a maths class.					
10. Studying for a maths test.					
11. Taking the maths section of a college/university entrance exam.					
12. Taking an examination (quiz) in a maths course.					

13. Picking up the maths text book to begin working on a homework assignment.					
14. Being given a homework assignment of many difficult problems which is due the next tutorial.					
15. Getting ready to study for a maths test.					
16. Dividing a five digit number by a two digit number in private with pencil and paper.					
17. Adding up 976 + 777 on paper.					
18. Reading a cash register receipt after your purchase.					
19. Figuring the VAT on a purchase that costs more than £1.00.					
20. Figuring out your monthly budget.					
21. Being given a set of numerical problems involving addition to solve on paper.					
22. Having someone watch you as you total up a column of figures.					
23. Totalling up a restaurant bill that you think overcharged you.					
24. Being responsible for membership fees for an organisation and keeping track of the amount.					
25. Studying for a driver's license test and memorising the figure involved, such as the distance it takes to stop a car going at different speeds.					
26. Adding up the money received and the expenses of a club you belong to.					
27. Watching someone work with a calculator.					
28. Being given a set of division problems to solve.					

29. Being given a set of subtraction problems to solve.					
30. Being given a set of multiplication problems to solve. 					

Appendix L: Eye-tracking setup and measures

This table summarises aggregated eye-tracking metrics and corresponding mathematics-anxiety (MARS) scores for each participant. Mean fixation duration and pupil size were analysed as indicators of attention and arousal during gameplay. Positive Δ Score values indicate a reduction in anxiety.

High-anxiety participants (P04, P08, P06) had longer fixation durations and larger pupil sizes, supporting the anxiety-attention link.

ID	Email ID	Blink Count	Fixations (Total)	Mean Fixation Duration (ms)	Mean Pupil Size	Saccades (Total)	Mean Saccade Amplitude (°)	MARS Before	MARS After	Δ Score (Before–After)
P01	rhiannon.williams96@gmail.com	219	2062	350.79	951.6	2062	3.31	80	68	12
P02	iamedinaperea1@sheffield.ac.uk	175	1590	168.48	556.6	1591	8.85	–	70	–
P03	awildman1@sheffield.ac.uk	130	2254	299.53	1302.6	2254	3.67	68	38	30
P04	lmsepulveda1@sheffield.ac.uk	248	2142	318.25	920.7	2142	3.50	123	69	54
P05	ekholland2@sheffield.ac.uk	160	1867	360.33	782.2	1867	3.16	72	62	10
P06	jhayes4@sheffield.ac.uk	312	1453	215.65	776.7	1453	5.87	91	76	15

P07	rmball1@sheffield.ac.uk	306	3794	243.46	818.9	3794	4.39	42	43	−1
P08	fsolanke1@sheffield.ac.uk	163	1486	210.79	819.7	1486	5.23	102	91	11
P09	sashworth1@sheffield.ac.uk	327	2729	294.68	703.1	2729	5.35	75	58	17
P10	rsuhailnuruddin1@sheffield.ac.uk	639	2124	200.63	912.2	2125	4.75	53	47	6
P11	jbraczka1@sheffield.ac.uk	88	2651	334.88	710.3	2651	4.87	31	37	−6
P12	l.fang@sheffield.ac.uk	364	3245	190.09	421.0	3245	4.88	66	66	0
P13	ekholland2@sheffield.ac.uk	434	1483	268.07	849.1	1482	5.73	72	62	10

Note: Participant 02 completed only the post-session MARS questionnaire; pre-test data unavailable.

Appendix M: Participant information sheet and consent form (if not confidential)

University of Sheffield - Information School: Information Sheet, Consent Form & Questionnaires

Title of research:

Educational computer games and their impact on maths anxiety in university students

Researcher:

Marc Bonne

What is the project's purpose?

To investigate the use of educational games in addressing mathematics anxiety among University of She eld social science students.

Do I have to take part?

It is up to you to decide whether or not to take part. If you do decide to take part please enter your email, sign the form below and click next. You can still withdraw at any time* without any negative consequences. You do not have to give a reason. If you wish to withdraw from the research, please contact Marc Bonne at: mabonne1@sheffield.ac.uk.

Why have I been chosen?

Students at the University of She eld studying social science subjects will be invited to take part due to previous studies by MASH (Mathematics and Statistics Help) demonstrating increased susceptibility to mathematics anxiety among the cohort. Around 30 students are expected to take part.

What will happen to me if I take part? What do I have to do?

The study will take place over 4 weeks.

You will be asked to complete a brief demographics questionnaire so that we have a pro le of all participants in the study.
This will be followed by an initial online mathematics anxiety rating scale. This is so we can collect data on your mathematics anxiety levels before playing the game.
You'll be asked to play an online browser-based maths game called "Algebra Meltdown". It's important that you do play the game once a day during the weekday (around 10 minutes or above is recommended). A separate Google "diary entry" form will be provided where you can make a note of the time you played, your experience playing the game, any maths you've done outside of the study, and how anxious you feel about maths after playing the game itself. Be sure to complete the form straight after playing. It should take no longer than 10 minutes to complete.

You'll be also be invited to take part in a 1 hour long playtest observation and interview (at your convenience, and is optional). This part of the study involves coming to the iLab at the University of She eld's Information School department. Here you'll be asked to play the Algebra Meltdown game for 30mins. Your gameplay, mouse movement, eye movement and facial reactions will be audio/video recorded, as well as your facial reactions. As this is a think-aloud study, you'll be encouraged to talk about how you feel while you play through the game. All of this will be used to identify signs of anxiety while you play as well as usability issues with the game.
The audio and/or video recordings of your activities during this research will be used only for analysis and for illustration in conference presentations and lectures. No other use will be made of them without your written permission, and no one outside the project will be allowed access to the original recordings.'
In the interview, you''ll be asked about your thoughts on the game from a usability perspective how you think each game has affected your maths anxiety levels. You may have video from the think-aloud study played back to you for clari cation purposes. The whole interview and observation process should take no more than an hour.
Near the end of the 4 week period, you'll receive an email invitation to take part in a nal online maths anxiety scale. This will help us compare your mathematics anxiety levels before the study and after. This is the nal part of the study.

What are the potential benefits of taking part?

Whilst there are no immediate bene ts for those people participating in the project, it is hoped that this work will...
- Feed into the development of a mathematics game that reduces mathematics anxiety.
- Contribute to the recognition and reduction of mathematics anxiety that persists in university courses.

For each weekday you take part you'll be entered into a prize draw to win a £10 Amazon voucher. Winner's will be selected at random and emailed their e-voucher code by 9am the next working day.

Please note, you can still enter the prize draw even if you need to withdraw from the study.

Who is organising and funding the research?

The research is not externally funded.

Who is the Data Controller?

This project has been ethically approved via the University of She eld's Ethics Review Procedure, as administered by the Information School department.

What if something goes wrong and I wish to complain about the research?

This project has been ethically approved via the University of She eld's Ethics Review Procedure, as administered by the Information School department.

Who has ethically reviewed the project?

The University of She eld will act as the Data Controller for this study. This means that the university is responsible for looking after your information and using it properly.

What are the disadvantages and potential risks of participating?

Though participants will be exposed anxiety playing the game, the risks of participating are the same as those experienced in everyday life.

What data will we collect?

The online demographic questionnaire will collect personal details such as name, age, gender, nationality, maths and computer games background. The maths anxiety scale will collect details of your maths anxiety levels. Alongside the post-test maths anxiety scale, you'll also be asked for the total time spent playing the game.

Will my participation be con dential?

All the information that we collect about you during the course of the research will be kept strictly con dential and will only be accessible to members of the research team. You will not be able to be identi ed in any reports or publications unless you have given your explicit consent for this. If you agree to us sharing the information you provide with other researchers (e.g. by making it available in a data archive) then your personal details will not be included unless you explicitly request this'.

What is the legal basis for processing my personal data?

According to data protection legislation, we are required to inform you that the legal basis we are applying in order to process your personal data is that 'processing is necessary for the performance of a task carried out in the public interest' (Article 6(1)(e)). Further information can be found in the University's Privacy Notice https://www.she eld.ac.uk/govern/data-protection/privacy/general.

What will happen to the data collected, and the results of the research project?

All of your data will be stored on the University of She eld's secure CICS research servers. The data will be accessible by the PhD researcher (Marc Bonne) and supervisors (Sheila Webber and Frank Hopfgartner - contact details below). Note that all data will be anonymised as it is collected.

The results of the research project will be written up in a doctoral thesis and is likely to be available via the university's institutional repository and accessible via the University's web pages within a year of completion of the study. Once published, you can obtain a copy of the results by emailing, mabonne1@she eld.ac.uk, or downloading a copy via the White Rose eThesis database: http://etheses.whiterose.ac.uk. The study may also be reported in academic and/or professional journals and/or conferences. In all of the aforementioned circumstances, the participant's name, a liation, position, and title will never be used in relation to any of the information provided.

All data will be destroyed 5 years after completion of the PhD. This will allow time for the data to be used for further journal/conference publications. In this period, it is very likely that other researchers may nd the data collected to be useful in answering future research questions. We will ask for your explicit consent for your data to be shared in this way.

What if something goes wrong and I wish to complain about the research?

If you wish to raise a compliment about the research, whether it's treatment by the researcher or something serious occurring during or following participation in the project, please contact Marc Bonne (mabonne1@she eld.ac.uk) or his supervisor Sheila Webber (s.webber@she eld.ac.uk). If you feel a complaint has not been handled to your satisfaction you can always contact the Head of Department, Peter Bath (p.a.bath@she eld.ac.uk) who will then escalate the complaint through the appropriate channels.

If the complaint relates to how your personal data has been handled, information about how to raise a complaint can be found in the University's Privacy Notice: https://www.she eld.ac.uk/govern/data-protection/privacy/general

Contact details:

If you have any questions or wish to discuss this study please email me, Marc Bonne at mabonne1@she eld.ac.uk, or call me at 07854805575.

You can also contact my supervisor Senior Lecturer at Information School, Sheila Webber at: s.webber@sheffield.ac.uk

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Never submit passwords through Google Forms.

Declaration

I, Marc Bonne, confirm that the Thesis is my own work. I am aware of the University's Guidance on the Use of Unfair Means (www.sheffield.ac.uk/ssid/unfair-means). This work has not been previously been presented for an award at this, or any other, university.