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Design and Evaluation of an Adventure Videogame Based in the History of Mathematics

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Abstract. The present paper describes the design and evaluation of an adventure videogame developed to cover the mathematics primary school curriculum. The narrative of the game is based in the history of mathematics and, to win, the player needs to travel through time, starting from the ancient Egypt and finishing at the modern world. To achieve that, the player interacts with real-life characters, such as Pythagoras of Samos, learning about their contributions to the field and using this knowledge to solve puzzles. The aim of the research presented in this paper is to understand the effects of the game on students' mathematics performance and levels of mathematics anxiety, a clinical condition where feelings of tension emerge during the manipulation of numbers. The game was tested by children from the first and second classes of Irish primary schools (n = 88). Students played the game for 3 weeks on weekly sessions of 45 min to 1 h. The experiment had a pre post-test design and students answered the Modified Abbreviated Math Anxiety Scale (mAMAS), and a mathematics test designed based on the content of the game. Statistical analysis suggested the game significantly improves students' mathematics performance. However, it increases the levels of mathematics anxiety on female students, opening discussion for considering what aspects of game design influences the levels of mathematics anxiety for this specific group.

Keywords: Mathematics anxiety · Primary school · History of mathematics

1 Introduction

International concerns about mathematics education involve factors related to children's poor level of understanding abstract concepts and their application to real life [1]. Traditional educational tends to focus on procedural and inflexible knowledge, leading students to look at mathematics as a cold-blooded subject that cannot be mastered by everybody. A research proposed 1,496 students from primary and secondary schools to write an essay with the theme "Me and Maths" [2]. The results suggest many of the essays are characterized by failures and unease, and students show a low perceived competence joint to the instrumental vision of mathematics. This is, according to the authors, reinforced by repeated experiences perceived as failures, when students feel they do not control their performance and conclude to be useless to work on it. Besides, students described they used to have a positive relationship with mathematics during

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primary school, but it became negative in secondary school. This can be related with the development of a clinical condition known as maths anxiety, a collection of negative feelings associated with activities that involve the manipulation of numbers and calculations [3, 4]. This condition can lead to poor performance at school and at work [5]. Different interventions are proposed to overcome or prevent mathematics anxiety, such as the adoption of a game-based learning approach. Educational games can bring maths to a context of problem-solving, making it more recognizable and less frightening. This paper contributes to exploring the impact of a mathematics videogame on learning outcomes and levels of anxiety. The game's narrative is based in the history of mathematics and allows the player learns mathematics while using it to solve problems.

2 Background

2.1 Learning Mathematics Through a Historical Perspective

Using the history as a teaching tool allows pupils to experience mathematics as a field that is constantly in development [6], avoiding them to think about mathematics as a given science ready to be used. Learning through history is not a new approach. In 1899, the Italian historian Gino Loria advocated for the use of a historical perspective in maths education, indicating teachers should adopt it to revisit elementary concepts. This helps students to understand that mathematics results of a contribution from different cultures, connects with other disciplines, and stimulates scientific, technical, artist and social development [7]. Other researchers consider using history as a tool to teach mathematics may motivate students while sustaining their interests and excitement [8]. Moreover, a historical approach humanizes mathematics, making it less frightening, and students may find comfort in knowing that concepts they find hard to learn took thousands of years to shape into their final form [9]. Today, the use of history to teach mathematics is part of initiatives from established organizations and is subject of conferences, papers and international discussions [10], such the History and Pedagogy of mathematics, a study group affiliated to the International Commission on Mathematical Instruction (ICMI) created in the 1970s. Still, teachers face some challenges while implementing this approach in their classroom. The time is already limited to the curriculum coverage and the addition of the history of mathematics may be time-consuming; besides, teachers find it hard to locate material about this topic [11]. This paper describes a game designed considering these and other challenges involved in the integration of history to mathematics.

2.2 Mathematics Anxiety and the Challenges Behind It

Due to a lack of understanding of how mathematics can be useful in daily life, students can feel frustrated and develop low confidence during the learning process. This can lead to the development of mathematics anxiety, a condition that can cause adverse effects on career choice and professional success [12]. A longitudinal study with 413 middle-school students showed that there is a significant growth of mathematics anxiety at the end of sixth grade, highlighting the importance of early interventions [13]. A variety of strategies have been studied in an attempt to prevent mathematics anxiety, such as guided imagery sessions [14], cognitive tutoring [15], mindfulness sessions [16], and games [17, 18]. Still, more research is needed to better comprehend how these interventions act and when they should be implemented. Researchers have identified that student's gender plays an important role in the levels of this condition. Female students tend to have higher levels of anxiety than male students [19, 20]. Besides, a study with second-grade students showed that the levels of mathematics anxiety only moderated mathematics performance in girls [21]. Therefore, early school interventions to reduce mathematics anxiety should also consider gender-specific aspects.

2.3 Learning Mathematics During the Primary School

The primary school level is essential for children's cognitive development. What a student learns during this phase of school can be crucial for later mathematics. For example, if a child cannot understand fractions during primary school, there are few chances of understanding simple algebraic equations in the future. This is shown by a longitudinal study designed and implemented by [22]. The study had two samples. The first sample had 3,677 students from the United Kingdom that had their mathematics proficiency assessed when they were 10 years old, followed by another test when they were 16 years old. The second sample had 599 students from the United States that had their mathematics proficiency tested when they were 10–12 years old and again when they were 15–17 years old. Both samples tested revealed that primary school students' knowledge about fractions and division uniquely predicted their knowledge and achievements in high school. Thus, it is important to invest in looking for strategies and solutions that can improve a better education in mathematics during the primary school.

3 Research Design

3.1 Description of the Game Design

The game designed and tested during this research is entitled Once Upon a Maths, a free adaptation of the historical facts as an attempt to give a meaningful background to mathematics. The game is composed of different phases containing short minigames. This allows teachers to adopt the game in the classroom even if they do not have a lot of time available. The player assumes the role of a time traveler protagonist, who decides to go back in time. To achieve that, the player should interact with ancient characters by watching animations where those characters describe how mathematics was used to solve daily life problems during their times. The animation not only ignites the narrative but also works as a brief tutorial to make clear to the player what is the aim of the minigame that follows that animation. The character then challenges the player to solve a challenge using what s/he just learned. If the player succeeds, the character gives him/her a passport stamp, allowing the player to move to the next phase of the game. The game can be accessed by any device with an internet connection and the child can play by opening a browser and typing the address to the game website. When accessing the game, the player finds a landing page where s/he can insert his/her details to log into the system. After that, the user has access to the page that shows 9 islands, each

Fig. 1. Landing page and phases page of Once Upon a Maths.

representing one of the challenges according to the historical period (Fig. 1). If the player is accessing the game for the first time, all levels will be locked except for the first one.

The first phase of the game presents the mathematics from ancient Egypt (3100 B.C.E – 30 B.C.E). It is hosted by Nebamun, a sculptor who invites the player to visit his house and presents the large collection of vases designed by himself. This phase contains 3 minigames and each one covers one concept from the Ancient Egyptian mathematics: the use of parts of the body to measure objects (Fig. 2), the use of maps, and the implementation of pieces of metal to weigh animals and food.

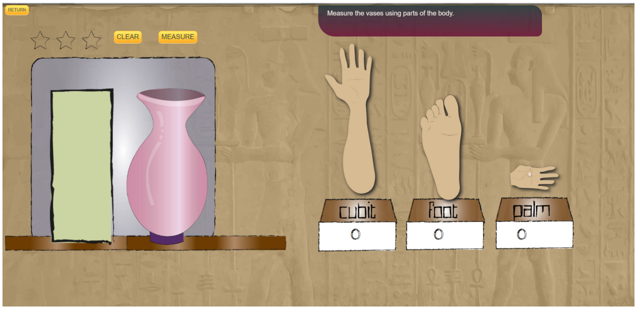

Fig. 2. In this minigame, student must measure the vase using parts of the body.

The second phase of the game comprises the mathematics from the ancient Greece period (1100 BC – 600 AD), presented by the philosopher Pythagoras of Samos, who describes the connection between mathematics and music. The animation was inspired by the registers that describe a moment where, while Pythagoras heard hammers in a blacksmith's forge and discovered that a balance between the hammers' weight resulted on a pleasant sound. This episode resulted on Pythagoras creating what is now known as music harmony. The 3 minigames of this phase challenges the player to play a song considering the relation between numbers and musical notes (Fig. 3).

The third phase of the game focuses on the mathematics concepts discovered in the Modern era (from the 19th century until nowadays), and the three minigames are open by an animation of the character Ada Lovelace, an English mathematician that is considered by many researchers the first computer programmer [23]. Lovelace explains what an algorithm is and tells a story from her childhood, when she was fascinated about the idea of flying [24]. The player is then challenged to use algorithms to teach an

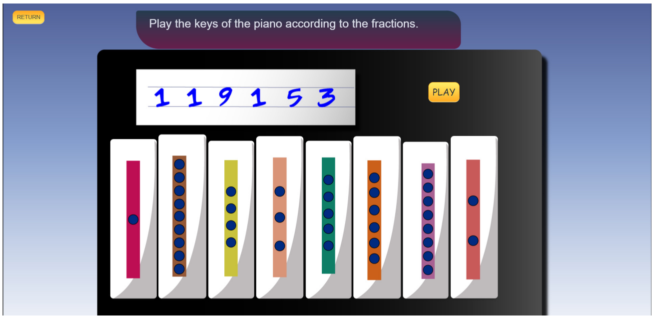

Fig. 3. The student has to play the piano according to the numerical music sheet.

animal how to fly. The minigames in this phase consist of dragging and dropping pieces of instruction to teach the animal how to fly among the clouds (Fig. 4).

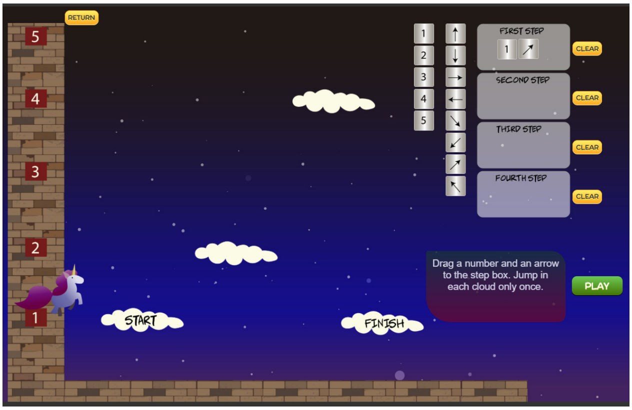

Fig. 4. One of the minigames from phase 3, where the player learns about algorithms.

3.2 Empirical Experiment

This research is motivated by the following research question (RQ):

RQ: What are the effects of a digital game based on the history of mathematics on the learning outcomes and anxiety in the primary school level?

Irish schools were recruited to be part of the experiment, which lasted 5 weeks. Each participant class was visited once per week and the visit had a duration between 45 min and one hour. The first visit consisted in a pre-test phase when students answered two questionnaires. The first is the modified Abbreviated Mathematics Anxiety Scale (mAMAS) [25], a reliable and validated questionnaire that measures the levels of mathematics anxiety in students from primary school. The second questionnaire consisted of a list of mathematics questions related to the content covered by the game, measuring students' performance on those topics. The mAMAS is based on the Abbreviated Math Anxiety Scale (AMAS) [26], and consists of a self-report questionnaire with nine items. Children use a 5-point Likert scale to indicate how anxious they feel when dealing with certain situations that involve maths, being 1 equal to low anxiety and 5 equals to hight anxiety. The higher is the result, the more anxious the child is. Both questionnaires were formatted so that it was more readable for young children, printed with large font size. The mAMAS included sad and happy emoticons at the endpoints of the Likert-scale to aid students in their responses. Each item of the mAMAS questionnaire was read out loud and the students answered the questions by themselves. The next three visits consisted of letting the students play each one of the three main phases of the game. In Ireland, the average class size is around 25 students [27]. Therefore, 30 tablets computers were brought to the classrooms for the game playing sessions. Students received printed passports with their username and password to access the game. The passport had three pages for students to get three different stickers as a reward for finishing each phase of the game, besides a page where they could get stickers for each colleague they helped. There was also a collection of pages for students to draw/register their adventure through the history of mathematics. Then, in the final fifth visit, students answered the mAMAS questionnaire again, and a modified version of the mathematics questionnaire. As participation was anonymous, researchers did not have access to students' names, only their game usernames. Teachers were responsible for filling a spreadsheet linking those details to students' usernames in the games, so researchers could link students' demographic data to their game performance and questionnaire results. The results were collected and inputted in a database and the analysis was carried out through statistics techniques using the software IBM SPSS Statistics 21. Statistics methods were applied to evaluate if Once Upon a Maths had any effect on the levels of maths anxiety of primary school students. First, Wilcoxon signed-rank test was conducted to evaluate if there was a significant difference between the pre and post-mAMAS test. Mann-Whitney U Test was used to evaluate if students' gender had an impact on the level of maths anxiety considering both pre and post-mAMAS tests. We also aimed to identify if Once Upon a Maths had any effect on students maths learning outcomes. The Wilcoxon signed-rank test was applied considering the pre and post-Maths test.

4 Results

Once Upon a Maths was tested by users in three different classrooms from two schools (Fig. 5). The first school is a catholic rural co-educational (mixed gender) school located in county Kildare, Ireland. It is a primary level school and has around 200 students registered currently. The game was played by 28 students from the second class of this school. The second school is also a catholic co-educational school. Located in Dublin, Ireland, this primary school has almost a thousand students enrolled currently. Two first class classrooms of this school played the game, in a total of 60 students. Therefore, a total of 88 students played Once Upon a Maths. From those students, 43 were females and 45 males.

Fig. 5. Students testing Once Upon a Maths.

4.1 Effects on the Game on Mathematics Performance

The Wilcoxon signed-rank test was also used to identify if Once Upon a Maths had any effect on students' performance in mathematics considering the pre and post-maths test. The test revealed a significant increase in maths performance after playing Once Upon a Maths ($z = -4.407$, $p < .001$, $r = .5$), with a medium effect. When evaluating if this increase of performance was significantly different considering gender (male and female) and maths performance group (low, medium and high), no significance was found (gender: $F(1, 67) = .953$ and $p > 0.05$; maths performance: $F(2, 67) = 2.699$ and $p > 0.05$).

4.2 Effects of the Game on Mathematics Anxiety

We evaluated students' levels of mathematics anxiety through mAMAS, a validated test designed for primary school students. The maximum score is 45, which results from the high level of mathematics anxiety, and the minimum is 1, resulting in a low level of mathematics anxiety. To identify if Once Upon a Maths has any effect on the levels of maths anxiety, statistical analysis was conducted to compare the pre and post-mAMAS test answered by the students. The test revealed no reduction in mathematics anxiety after playing Once Upon a Maths ($z = -1.242$, $p = .214$). However, considering the gender, there was a significant increase in the level of mathematics anxiety for the female group of students, with $F(1, 71) = 12.480$ and $p = 0.001$.

5 Conclusions

The novelty of this research consists of evaluating the use of a game based on the history of maths as a tool to improve learning outcomes and reduce anxiety. Games, in general, are a great way to approach the development of deep thinking and, if there is a good narrative behind them, to show how certain puzzles represent real-life challenges. Once Upon a Maths significantly increased the learning outcomes, which might be related to the fact narrative-based learning leads students to connect the concepts learned to the human experience [28], which can result in making abstract concepts more meaningful.

Once Upon a Maths did not affect the levels of maths anxiety considering the whole group of students but seems to increase those levels for female students. The gender differences about maths anxiety are already well described [29] and it is known that girls tend to be more anxious than boys, even when they have similar levels of performance [21]. Once Upon a Maths considered design principles that make the game more attractive to girls, like high use of visual learning approach [30], storytelling elements [31], and reduction of competitiveness [32]. Many reasons should be considered to explain why girls tend to have a higher level of mathematics anxiety than boys. Exposure to negative attitudes about maths by role models like parents and teachers, a higher possibility of feeling anxious when seeing another child with anxiety, and exposure to gender stereotypes are only a few reasons that might lead girls to have higher anxiety than boys [21, 33, 34]. The way students build their social relationships plays huge importance in their learning outcomes [35], further studies should evaluate the role social aspects play on the levels of maths anxiety.

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