
Doctoral

Science

2020-5

Investigation of the Effects of a Situated Learning Digital Game on Mathematics Education at the Primary School Level

Mariana Rocha

Follow this and additional works at: <https://arrow.tudublin.ie/sciendoc>



Part of the [Computer and Systems Architecture Commons](#)

This Theses, Ph.D is brought to you for free and open access by the Science at ARROW@TU Dublin. It has been accepted for inclusion in Doctoral by an authorized administrator of ARROW@TU Dublin. For more information, please contact arrow.admin@tudublin.ie, aisling.coyne@tudublin.ie.



This work is licensed under a [Creative Commons Attribution-Noncommercial-Share Alike 3.0 License](#)



**Investigation of the effects of a situated learning
digital game on mathematics education at the
primary school level**

Mariana Rocha

Thesis submitted for the degree of *Doctor of Philosophy*

Supervisors: Dr Pierpaolo Dondio

Professor Brendan Tangney

School of Computer Science

Technological University Dublin

May 2020

Abstract

Previous research suggests games can improve learning outcomes and students' motivation. However, there still exists insufficient clarity on the design principles and pedagogical approach that should underpin mathematics educational games. This thesis is aimed at evaluating the effects of an educational game on the learning performance and levels of anxiety promoted by mathematics activities of primary school students. The game was designed based on the principles of situated learning, following a combination of an in-depth literature review, a collection of teachers' perceptions about educational games, and features of classroom games. Empirical evaluation of the game was performed through a 5-weeks experiment carried out in three Irish schools, with the participation of 88 students. The investigation had a pre-post-test design and aimed to evaluate the effects of the game on students' mathematics performance and anxiety. In the first week, students answered the Learning Outcomes on Mathematics for Children (LOMC), a questionnaire that measured students' knowledge of mathematics. The same students also answered the Modified Abbreviated Math Anxiety Scale (mAMAS), a validated self-report questionnaire to assess maths anxiety of primary school children. During the following three weeks, students had weekly gameplay sessions of 45-60 minutes. In the last week, students answered a modified version of the LOMC and the same version of the mAMAS, besides participating in group interviews performed to gather their perceptions about the game. Comparison of pre and post-tests results through Wilcoxon signed-rank test suggested the game significantly improved students' maths performance in two of the three classrooms. No significant changes in the levels of maths anxiety were identified after playing the game. However, Analysis of covariance (ANCOVA) suggests that, in one of the three classrooms, female students had higher levels of maths anxiety after playing the game. The present research contributes to the body of knowledge clarifying the effects of situated learning game adoption of mathematics performance and anxiety of primary school children. This research brings possibilities for future work on understanding the gender differences when playing games to reduce levels of mathematics anxiety.

Declaration

I certify that this thesis which I now submit for examination for the award of Doctor of Philosophy is entirely my own work and has not been taken from the work of others, save and to the extent that such work has been cited and acknowledged within the text of my work. This thesis was prepared according to the regulations for graduate study by research of the Technological University Dublin and has not been submitted in whole or in part for another award in any other third-level institution.

The work reported on in this thesis conforms to the principles and requirements of the TU Dublin's guidelines for ethics in research.

TU Dublin has permission to keep, lend or copy this thesis in whole or in part, on condition that any such use of the material of the thesis be duly acknowledged.

Signature Mariana Rocha Date 01/05/2020

*“While we have each other, we will **never** be alone. And, when we don’t, we will always have the **light**. Always.”*

Aline Machado

Acknowledgements

First, I would like to sincerely express my gratitude to my supervisor Dr Pierpaolo Dondio, for his enormous patience, guidance and knowledge, and for believing I could do it. I could not expect to have a better supervisor. In addition, I am grateful for his family support, Ilaria, Elisa, Beatrice and Francesco were an unexpected gift this PhD has brought me.

I am grateful to my family, who, ten thousand kilometres away, supported me through the long video calls and infinite text messages. Mom, dad, Lucas, grandmas Margarida and Dalva, uncle Edson, auntie Rosa, Edirene, António, cousin Carlos Alberto, and so many others: this is for you. Thank you also to my sisters Aline, Rafaela, Marcelle, Marina, and Natalia, for the love and dedication that proves we can fly together even when we are apart.

Thank you to my Brazilian family in Ireland, Lud, Diego and Camilo, who held my hand during these four years. Thanks for the laughs, games, hugs, and lots of pizza.

To my big ESHI community: thank you a million times, especially for the surprise birthday Skype party during the lockdown! To Aitor for the long talks about science, philosophy, and dreams (and for the maze)! To Rashmi, for the smiles and fantastic advice. To Camila and Gerald for making me feel at home in your house. To Josi, Morgana, Francisco, Paula, Gabi, Jessica, Fernando, Heta, Hani, Hicham, Paul, Kevin, Padraic, and so many friends from different parts of the world. Thank you for sharing your journey with me.

Thank you to all the School of Computer Science staff, in particular, Professor Sarah Jane, for supporting me during this journey. Thank you, Ireland, for making it possible. And, finally, thank you to all the children and teachers that helped this research and played this game. You made a dream come true.

Table of contents

| | |
|---|-----------|
| List of acronyms..... | 25 |
| Publications related to this thesis | 26 |
| List of figures | 27 |
| List of tables | 30 |
| 1 Introduction | 16 |
| 1.1 Learning through games | 16 |
| 1.2 Anxiety and learning | 18 |
| 1.3 Problem statement and research question | 20 |
| 1.4 Research methodologies, methods, and objectives | 20 |
| 1.5 Expected contribution to the Body of Knowledge | 23 |
| 1.6 Thesis structure | 24 |
| 2 Literature review | 25 |
| 2.1 Digital Game-Based Learning..... | 26 |
| 2.1.1 Applications in the classroom | 28 |
| 2.1.2 Focus in primary school..... | 32 |
| 2.1.3 The specific case of mathematics learning..... | 33 |
| 2.2 Situated Learning..... | 38 |

| | |
|--|-----------|
| 2.2.1 Applications..... | 40 |
| 2.2.2 Design principles | 41 |
| 2.2.3 Digital Game-Based Situated Learning..... | 44 |
| 2.3 Learning through a historical perspective..... | 50 |
| 2.3.1 Implementations in the classroom | 50 |
| 2.3.2 Application in digital games..... | 51 |
| 2.3.3 The specific case of mathematics | 52 |
| 2.4 Summary and gaps in the literature..... | 54 |
| 3. Research design..... | 56 |
| 3.1 Problem statement and research hypothesis | 56 |
| 3.2 Process of design and development of the game..... | 56 |
| 3.2.1 Preliminary multidimensional self-reporting survey on game-based learning.... | 57 |
| 3.2.2 Theoretical game development framework..... | 67 |
| 3.2.3 Practical and technical implementation..... | 93 |
| 3.3 Empirical experiment..... | 124 |
| 3.3.1 Questionnaires | 126 |
| 3.3.2 Primary schools' selection..... | 128 |
| 3.3.3 Participants, procedures, and ethics | 128 |
| 3.4 Evaluation | 129 |
| 3.4.1 - Internal reliability of preliminary self-reporting survey via Cronbach Alpha . | 129 |

| | |
|--|------------|
| 3.4.2 Overall comparisons..... | 130 |
| 3.4.3- Assumptions checking of inferential statistics for LOMC and mAMAS | 130 |
| 3.4.4 - Hypothesis testing..... | 130 |
| 3.4.5 - Qualitative evaluation with group interviews..... | 131 |
| 3.5 Strengths and limitations | 132 |
| 4 Results | 134 |
| 4.1 Descriptive statistics and demographics..... | 134 |
| 4.2 Inferential statistics on overall comparisons..... | 138 |
| 4.2.1 Effects on the levels of maths anxiety..... | 139 |
| 4.2.2 Effects on mathematics performance..... | 140 |
| 4.3 Inferential statistics on class-specific comparisons..... | 141 |
| 4.3.1 Classroom 1 (1 st class)..... | 141 |
| 4.3.2 Classroom 2 (1 st class)..... | 142 |
| 4.3.3 Classroom 3 (2 nd class)..... | 144 |
| 4.4 Group interviews | 145 |
| 4.5 Hypothesis testing and discussion..... | 149 |
| 4.6 Strengths and limitations of findings..... | 152 |
| 5 Conclusion..... | 154 |
| 5.1 Thesis summary..... | 154 |
| 5.2 Contribution to the body of knowledge..... | 155 |

| | |
|---|------------|
| 5.3 Future work..... | 157 |
| 5.4 Final remarks..... | 159 |
| References | 160 |
| Appendices | 198 |
| Appendix 1 - Preliminary multidimensional self-reporting survey on game-based learning | 198 |
| Appendix 2 - Group interview questions..... | 208 |
| Appendix 3 - Learning Outcomes in Mathematics for Children | 209 |
| Appendix 4 - Abbreviated Mathematics Anxiety Scale (mAMAS) | 211 |
| Appendix 5 - Schools' recruitment letter | 212 |
| Appendix 6 – Parent/Guardian's letter of consent..... | 216 |
| Appendix 7 - Transcription of group interviews..... | 218 |

List of acronyms

DGBL Digital Game-Based Learning

GDP Gross Domestic Product

ICT Information and Communications Technology

ICMI International Commission on Mathematical Instruction

ITS Intelligent Tutoring System

LOMC Learning Outcomes in Mathematics for Children

mAMAS Modified Abbreviated Math Anxiety Scale

NCCA National Council for Curriculum and Assessment

Publications related to this thesis

Rocha, M., & Dondio, P. (2020). Design and evaluation of an adventure videogame based in the history of mathematics. In *9th International Conference GALA 2020*. Laval, France: Springer.

Rocha, M., Tangney, B., & Dondio, P. (2016). A survey of digital games used in Irish Schools: the drill-and-practice has turned digital. In P. Felicia, N. Pierce, M. Brady, & A. Devitt (Eds.), *6th Irish Conference on Game-Based Learning* (pp. 53–60). Dublin: CreateSpace Independent Publishing Platform.

Rocha, M., Tangney, B., & Dondio, P. (2018). Play and Learn: Teachers' Perceptions About Classroom Video Games. In M. Ciussi (Ed.), *Proceedings of the 12th European Conference on Games Based Learning* (pp. 808–816). Sophia Antipolis: ACPI.

List of figures

| | |
|---|-----|
| Figure 1 Structure of the research design..... | 21 |
| Figure 2 Three-pillars of the literature review. | 25 |
| Figure 3 Elements of situated learning design of multimedia (Herrington and Oliver, 1995) | 43 |
| Figure 4 three components considered during the game design phase..... | 57 |
| Figure 5 Demographic categories of the participants of the Preliminary Multidimensional Self-reporting Survey on Game-based learning | 60 |
| Figure 6 Theoretical Game Development Framework – categories of game pedagogy element | 70 |
| Figure 7 Theoretical Game Development Framework – categories and subcategories of the Game design element. | 80 |
| Figure 8 Theoretical Game Development Framework: Game Technical Features | 85 |
| Figure 9 Once Upon a Maths’ passports. | 96 |
| Figure 10 Visual feedback is given when the player makes a mistake on minigame 7..... | 97 |
| Figure 11 Landing page of once upon a maths game. | 99 |
| Figure 12 Levels page | 100 |
| Figure 13 The Elemental Tetrad by Schell (2014). | 101 |
| Figure 14 Nebamun is the character from the Ancient Egypt phase. | 102 |
| Figure 15 The animation compares the parts of the body measurements with the size of the animals | 103 |
| Figure 16 In minigame one, the player uses parts of the body to measure vases..... | 104 |
| Figure 17 In minigame one, if the player wins, the vase goes down the platform. | 104 |

| | |
|---|-----|
| Figure 18 In minigame one, if the player loses, the vase breaks. | 105 |
| Figure 19 The second animation introduces the concept of coordinates and maps. | 105 |
| Figure 20 In minigame two, the player brings the vase to the right place based on the coordinates..... | 106 |
| Figure 21 Screenshot of minigame two when the player succeeds. | 107 |
| Figure 22 The third animation introduces the weighing system adopted during Ancient Egypt. | 108 |
| Figure 23 In minigame three, the player should find the balance between the pieces and the animal..... | 108 |
| Figure 24 If the pieces are too heavy, the animal spins away | 109 |
| Figure 25 The fourth animation introduces the connection between music and maths..... | 110 |
| Figure 26 In minigame four, the player should organize the notes by size. | 111 |
| Figure 27 In minigame five, the player should match the pieces with the music sheet. | 112 |
| Figure 28 In minigame six, the player follows the music sheet to play a song..... | 113 |
| Figure 29 In the fifth animation, Ada Lovelace explains how algorithms work..... | 114 |
| Figure 30 In minigame seven, the player describes an algorithm to teach the animal how to fly. | 115 |
| Figure 31 In minigame eight, the player should avoid the dark cloud. | 116 |
| Figure 32 In minigame nine, the player should avoid even number clouds..... | 116 |
| Figure 33 Splash page of Once Upon a Maths | 119 |
| Figure 34 Colour scheme of Once Upon a Maths phase 1..... | 119 |
| Figure 35 Phase 1 was inspired by real-life Ancient Paintings (Source: Oakes and Gahlin, 2018, p. 419)..... | 120 |

| | |
|--|-----|
| Figure 36 The scale presented in minigame three was inspired by a real Ancient painting (Source: The Papyrus of Hunefer, 1275 BCE)..... | 120 |
| Figure 37 Colour scheme of Once Upon a Maths phase 2..... | 121 |
| Figure 38 The phase 2 character represents Pythagoras of Samos..... | 121 |
| Figure 39 Colour scheme of Once Upon a Maths phase 3..... | 122 |
| Figure 40 Ada Lovelace character was designed based on paintings from her times, like this one by Alfred Edward Chalon (Source: Public domain). | 122 |
| Figure 41 Steps of the empirical experiment..... | 125 |
| Figure 42 Students are testing Once Upon a Maths..... | 134 |
| Figure 43 Students drew their memories on the passports..... | 148 |

List of tables

| | |
|--|-----|
| Table 1 Questions included measuring teachers' perceptions of classroom games..... | 59 |
| Table 2 Teachers' level of agreement with statements about the use of digital games for education. | 61 |
| Table 3 Reasons cited by respondents' teachers for not using games in the classroom. | 62 |
| Table 4 Multicollinearity diagnosis of Likert scale questions. | 64 |
| Table 5 Logistic regression predicting the likelihood of digital game use in the formal environment..... | 66 |
| Table 6 Frequency of classroom games classified by the elements of the Game Pedagogy section of the framework..... | 88 |
| Table 7 Game design element application to classroom videogames. | 90 |
| Table 8 Game technical features application to classroom videogames..... | 92 |
| Table 9 Once Upon a Maths curriculum coverage. | 94 |
| Table 10 Number of students per school considering gender. | 135 |
| Table 11 Classification according to mathematics grade..... | 135 |
| Table 12 Distribution of students according to performance classification..... | 136 |
| Table 13 Distribution of students according to the performance considering the gender. . | 136 |
| Table 14 Distribution according to the mean, standard deviation, and percentiles of the pre- and post-mAMAS and pre-and-post-LOMC..... | 137 |
| Table 15 Distribution of pre- and post-mAMAS and pre- and post-LOMC results according to students' gender..... | 138 |
| Table 16 Summary of the results of the empirical experiment. | 145 |

1 Introduction

This thesis presents the development of a PhD research that aimed to comprehend the effects of a situated learning videogame on mathematics performance and levels of mathematics anxiety in primary school children. The following chapter brings an introduction to concepts relevant to the present research.

1.1 Learning through games

The adoption of video games to improve the learning process is part of a research area entitled Digital Game-Based Learning (DGBL). Since at least mid-60s, the potential of using digital games on education has been discussed in the academic journals (Eck and Dakota, 2007). Research has shown that video games benefit education as they are user-centred and “promote challenges, co-operation, engagement, and the development of problem-solving strategies” (Gros, 2007), as well as promoting collaborative work among players (Baek, 2010). The studies of DGBL are distributed over many disciplines, and the present thesis aims to contribute to the body of knowledge about the adoption DGBL to improve mathematics education. While stimulating the development of problem-solving and critical thinking skills, digital games support students to comprehend better abstract mathematics concepts (Bruce D. Homer, Charles Raffaele, 2020). Digital games also have proved to be able to increase students’ positive attitudes towards maths (Ke and Building, 2006; Afari *et al.*, 2013), making the subject less frightening and getting students motivated to learn.

The adoption of digital games to teach mathematics is also in line with current trends of mathematics education. During the last 40 years, researchers have been looking for

strategies to take mathematics away from abstract calculations and bring it into a context. As digital games can simulate different problem-solving scenarios, students have access to immersive situations where mathematical concepts should be applied to solve contextualized challenges. In the present research, this is done by presenting students problems faced by characters that were part of the history of mathematics, another well-studied tool that allows learning maths inside a context. According to (Karaduman, 2010a), “historical analysis has been the basis for the theory that mathematics should be related to life situations” (p. 2689), as the great civilizations developed this science to solve economic and social problems of their times. Moreover, the history of mathematics “lets children experience that mathematics is always developing, that it is continuously changing and that they are part of this evolution” (p.19, Kool, 2003).

The efficiency of a digital game based on the history of mathematics will be assessed by looking at students’ mathematics performance. Previous research suggests that digital games can improve primary school students mathematics skills, such as number line estimation (Vanbecelaere *et al.*, 2020); strategic and reasoning abilities (Bottino *et al.*, 2007); visuospatial abilities (Freina, Bottino and Ferlino, 2018); and arithmetic performance (Núñez Castellar *et al.*, 2015). Digital mathematics games can promote higher learning gains when compared to other teaching strategies (Tokac, Novak and Thompson, 2019).

Digital games can also motivate students to learn mathematics and enhance their confidence and engagement (Ku *et al.*, 2014; Gil-Doménech and Berbegal-Mirabent, 2017). Students’ confidence plays an essential role in the second metric used to evaluate the efficacy of the history-based game evaluated by the present research: the levels of maths anxiety. Maths anxiety is a collection of negative feelings associated with activities that involve the manipulation of numbers and calculations (Jansen *et al.*, 2013; Caviola *et al.*, 2017).

Although maths anxiety does not affect only students with poor performance, it is a condition associated with low maths learning results (Chang and Beilock, 2016). Maths anxiety can also lead to a lack of confidence, resulting in adverse effects on career choice and professional success (Ma, 1999).

1.2 Anxiety and learning

The lack of confidence while dealing with challenging subjects can lead students to develop anxiety. This aversive motivational state occurs when the level of perceived threat is high, leading the individual to avoid that situation (Calvo and Eysenck, 1992). Although a certain level of anxiety is naturally part of children's development, approximately 3-24% of children below 12 years old experience anxiety problems that interfere their daily life (Cartwright-Hatton, McNicol and Doubleday, 2006). Children with low levels of anxiety tend to feel more competent and more assertive academically than children with average or high levels of this condition (Mammarella *et al.*, 2018). The levels of general anxiety tend to correlate with the school performance negatively, and this correlation already appears during the primary school years (Mazzone *et al.*, 2007). The association between learning disabilities and emotional problems have been identified at the beginning of the 1900s as students with learning disabilities tend to have higher scores of anxiety than others (Nelson and Harwood, 2011). Academic anxiety related to learning can appear during the early stages of school life. Negative attitudes towards mathematics and science can start even before students enter kindergarten (Geist, 2019).

Maths anxiety is an enduring type of anxiety that represents a reasonably stable characteristic of an individual (Luttenberger, Wimmer and Paechter, 2018). Currently, the theories designed to explain maths anxiety causes fall into three main categories: poor maths

skills (Ma and Xu, 2004), genetic predispositions (Wang *et al.*, 2014), or socio-environmental factors (Vukovic, Roberts and Green Wright, 2013). Socioenvironmental factors are related to the context where the child exists and learn, considering, for instance, the influence of parents who are also anxious about the subject of mathematics. Previous research proved the existence of an intergeneration transmission of maths anxiety, so parents with high levels of this condition tend to raise children that also develop it and have poor performance in mathematics (Maloney *et al.*, 2015). Even though parents with maths anxiety may result in mathematically anxious children, family support is relevant to the learning process. Studies suggest that the levels of maths anxiety could be reduced in children that have parent's support while studying the subject at home (Vukovic, Roberts and Green Wright, 2013).

Although it is not clear what causes maths anxiety, researchers have found that student's gender plays an essential role in this condition. Female students tend to have higher levels of anxiety than male students (Hunsley and Flessati, 1988; Rubinsten, Bialik and Solar, 2012). A study with second-grade students suggested that the levels of maths anxiety only moderated maths performance in females (Van Mier, Schleepen and Van den Berg, 2019). Therefore, early school interventions to reduce maths anxiety should also consider gender-specific aspects. A variety of strategies has been studied as an attempt to prevent or minimise maths anxiety, such as guided imagery sessions (Henslee and Klein, 2017), cognitive tutoring (Supekar *et al.*, 2015), mindfulness sessions (Samuel and Warner, 2019), and games (Verkijika and De Wet, 2015; Reyes, 2019). Still, more research is needed to comprehend better how these interventions act and when they should be implemented (Maloney, Schaeffer and Beilock, 2013; Ramirez, Shaw and Maloney, 2018). A longitudinal study with 413 middle-school students showed that there is a significant growth of maths anxiety levels at

the end of sixth grade, highlighting the importance of early interventions (Madjar *et al.*, 2018).

1.3 Problem statement and research question

Digital Game-Based Learning has been studied as a way of increasing the quality of the learning process. However, few is known about the effects of DGBL on the levels of maths anxiety. The present research aims to investigate the results of a DGBL on the process of mathematics learning during the primary school years. Following the gaps emerged in the literature, the following research question (RQ) is set:

RQ: What are the effects of an educational digital game on the levels of mathematics performance and mathematics anxiety during the beginning of primary school?

The research hypothesis considers that a digital game, when developed based on pedagogical principles, can improve students' maths performance, and reduce the levels of maths anxiety. The following section describes the process adopted to test this hypothesis.

1.4 Research methodologies, methods, and objectives

The design of the present research starts from an exploratory phase. During this stage, the aim is to identify the nature of the problem to be solved, including a literature review to comprehend better the field and previous solutions developed by other researchers. This phase also includes mapping teachers' point-of-view about games and an evaluation of a collection of the games used by these teachers. Following that, a design and development phase comprises, based on the information collected during the exploratory phase, in developing a game that can shed light on the link between playing videogames and the levels of maths anxiety and performance. The next stage, the Testing/Experimental Phase, includes

the implementation, testing and evaluation of the game by primary school students in a classroom environment. The following diagram (Figure 1) shows how the research process is structured as an attempt to answer the thesis research question.

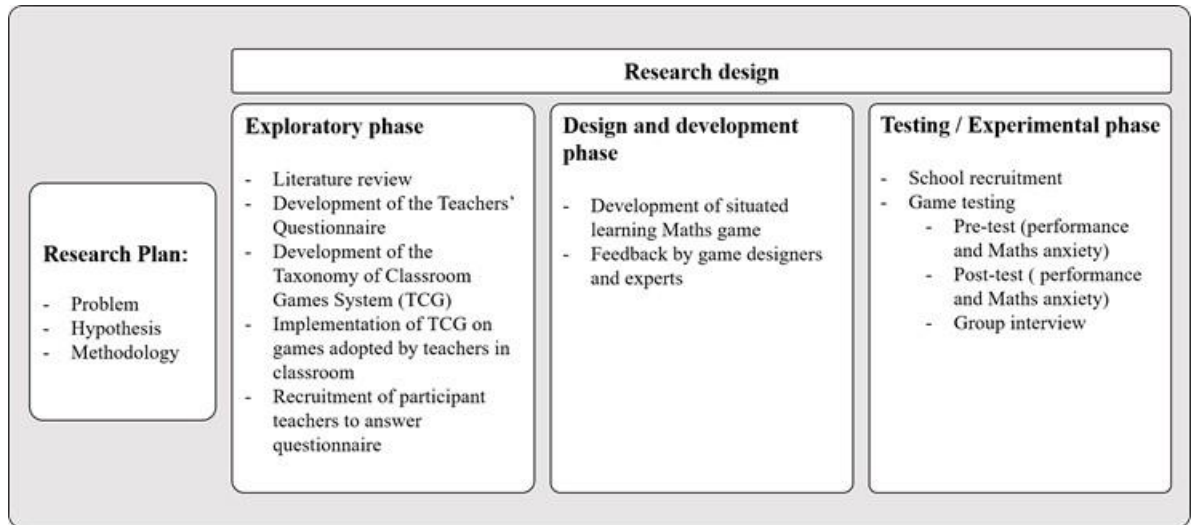


FIGURE 1 STRUCTURE OF THE RESEARCH DESIGN.

A set of research objectives and sub-objectives is defined to answer the research question:

O1. To understand the state-of-the-art on the adoption of DGBL in the classroom.

(a) To investigate and review the central notions, theories, applications, and ideas of DGBL for formal education.

(b) To evaluate the patterns of DGBL adoption by teachers in the formal educational environment.

O2. To collect data that support the design and development of educational digital games for mathematics learning.

- (a) To review educational theories and design principals that support educational digital games.
- (b) To collect information about digital games currently adopted by teachers.
- (c)

O3. To design an experiment and collect empirical data about DGBL in mathematics education at the primary school classroom.

- (a) To implement the design principles previously selected and develop a mathematics educational digital game.
- (b) To identify methods of assessing the effects of digital games on mathematics performance and maths anxiety.
- (c) To recruit primary schools and collect data about the impact of DGBL in the classroom considering mathematics performance and levels of maths anxiety.

This research is inductive and starts from observing the efficacy of DGBL in enhancing the mathematics learning process in formal education when the games are designed considering particularities of the classroom environment. This observation results on the attempt of formulating the hypothesis that digital games underpinned by pedagogical strategies already used in mathematics learning, such as the historical approach, can improve the learning outcomes and reduce the levels of maths anxiety.

A literature review partially achieves objectives 1 and 2. Previous evidence of design principles that resulted in efficient educational digital games is collected. Pedagogical theories and approaches are also selected to underpin the game to be developed during the present thesis. The first two objectives are also achieved by the implementation of a survey that aims to collect teachers' perceptions about games and the names of digital games those teachers implement in their classrooms. A framework will be designed and developed to classify those games and collect knowledge about the main features of those games. Objective 3 is achieved based on data collected from objectives 1 and 2. A digital game will be designed and developed to be implemented at mathematics primary school classrooms in order to understand its effects on mathematics performance and levels of students' mathematics anxiety.

1.5 Expected contribution to the Body of Knowledge

The present thesis aims to contribute to the field of game-based learning by the evaluation of a digital game on mathematics performance and levels of maths anxiety in primary school.

Theoretical contributions

This research aims to collect data about game design elements that play a significant role in mathematics education, considering the previous literature, teachers' perceptions and other educational games. The findings will contribute to understanding aspects that play a crucial role in terms of learning through the digital game, especially considering maths performance and anxiety levels.

Practical contributions

This study will:

- Identify teachers' perceptions of educational games and their use in the classroom.
- Deliver an educational maths game to be played by primary school students. The game will be aligned with the official school curriculum and underpinned by pedagogical theories and strategies.
- Empirically evaluate the potential of an educational digital game as a maths learning tool for primary school students, considering maths performance and levels of maths anxiety.

1.6 Thesis structure

This thesis is divided into five chapters. The current chapter introduces the content, while Chapter 2 brings a literature review covering the main concepts related to this research. It summarises information about the main ideas of DGBL and its application in mathematics education, the potential of learning through the history and how digital games can play a role in this approach, and a summary of the gaps on previous research. Chapter 3 brings details about the design of the present study, considering the problem statement and the methods used to develop the game better, and details about the empirical experiment used to evaluate the game. Chapter 4 describes the results of the research, detailing the implementation and analysis of the game in a primary school classroom. Chapter 5 concludes the thesis with a summary of the work and discussions of how the results found are aligned with previous research, besides describing the research limitations and potential future work.

2 Literature review

The present chapter brings information about the use of digital games in the classroom, describing how they have been implemented so far and what types of pedagogical theories and strategies can underpin the adoption of videogames for education. This chapter also brings an outline of concepts and previous researches related to the three pillars that support the design of the videogame evaluated in this thesis: the digital game-based learning, the situated learning, and the history of mathematics (Figure 1).

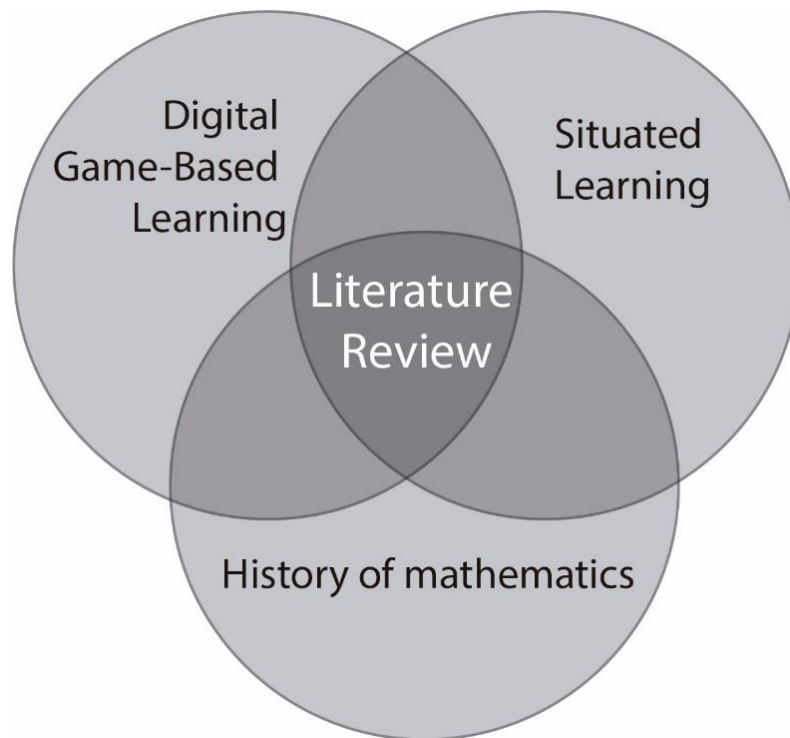


FIGURE 2 THREE-PILLARS OF THE LITERATURE REVIEW.

2.1 Digital Game-Based Learning

Digital Game-Based Learning is the adoption of games as support for formal and informal learning. As suggested by Logan & Woodland (2015), game-based learning is a branch of serious games that deals with defined learning outcomes, focusing on principles like motivation, complex decision making and social experiences. Tang, Hanneghan, & Rhalibi (2009, p.1) describe game-based learning as “the innovative learning approach derived from the use of computer games that possess educational value or different kinds of software applications that use games for learning and education purposes such as learning support, teaching enhancement, assessment and evaluation of learners”. According to Gee (2008, p. 21) “good game design has a lot to teach us about good learning”. The game-based learning incorporates the use of games designed expressly with learning goals and also the implementation of entertaining games to the educational context (Kirriemuir and McFarlane, 2004). In a more detailed description, Van Eck (2006) suggests that there are three ways of practising game-based learning: through students creating their games, using serious games, or with the implementation of commercial off-the-shelf games to the learning context. Nevertheless, when used to support teaching and learning in a formal environment, such as schools and universities, serious games are called educational games. Dörner et al. (2016) define educational games as a subgroup of serious games, “tackling the formal educational sector from elementary schools to higher education, vocational training, and collaborative workplace training”.

Michael & Chen (2006) argues that serious games, differently from other games, do not have enjoyment, entertainment, and fun as primary purposes. Past definitions assume serious games are not designed for players to have fun. As the field of learning games

developed, the element fun started to be included as an essential element of educational games. Giannakos (2013) evaluated how factors such as enjoyment and happiness, influenced 13 years old students while playing a mathematics game. The research suggested that the more students enjoyed the game, the better was their performance in a mathematics test answered after playing the game. Iten & Petko (2016)'s experiment suggests the opposite. The researchers implemented an educational game for 10-13-years-old students. The objective of the game was to teach about awareness and critical thinking when using the internet, showing how to avoid contents that are inappropriate for young people. The results suggested that the enjoyment element of the game influenced players' motivation but did not have any significant effect on the learning gains.

Although the role of fun in educational games might not be exact, more recent definitions consider it as an important dimension of serious play. Dörner, Göbel, Effelsberg, & Wiemeyer, (2016) described serious games as tools designed with the objective of entertaining and to achieve at least one extra goal, such as learning or health – to the authors, the fun element plays an important role even on serious games. The importance of fun might be more evident when entertainment games are implemented in a serious context. A study of Charsky & Ressler (2011) examined students' motivation to learn while playing the entertaining game Civilization III (2001). This commercial game is designed with no educational goals, but its narrative has the potential for teaching concepts related to History. Charsky and Ressler (2011) tested the game with two different groups: one received a list of history concepts, and then played the game, while the other played the game but had to look for the list of ideas in a concept map or design their concept map. The use of concept maps decreased students' motivation to learn through gameplay. The authors believe that it

happens because the concept map brought students' attention to the difficulty of the subject, and made the game less autonomous and creative, negating the fun side of serious games. A lot of effort is being made to deliver design guidelines for the developments of serious educational games. Unfortunately, designers might develop exciting and fun games but much neglecting instructional material with consequences on learning (Tahir and Wang, 2020), while educators struggle in finding the balance between the fun element of the game and the curriculum content covered by the game (Gros, 2016).

2.1.1 Applications in the classroom

Nowadays, game-based learning can support formal education at different school levels, besides improving students' learning outcomes in fields like science (Hwang, Wu and Chen, 2012; Lester *et al.*, 2014), mathematics (Núñez Castellar *et al.*, 2015; McLaren *et al.*, 2017; Kiili, Moeller and Ninaus, 2018) and language learning (Berns, Gonzalez-Pardo and Camacho, 2013; Yeh, Hung and Hsu, 2017). Moreover, a variety of skills can also be obtained through the use of serious games for education, such as problem-solving (Sánchez and Olivares, 2011; Al-Washmi, Hopkins and Blanchfield, 2013; Sun, Chen and Chu, 2018) and critical thinking (Yi, 2011; Checa-Romero, 2016). Classroom games are also able to increase students' engagement and interest. Game-based student response systems, such as Kahoot!, can improve students interaction and promote active participation in the classroom (Plump and LaRosa, 2017; Orhan Göksün and Gürsoy, 2019).

Research has shown that videogames benefit education as they are user-centred and “promote challenges, co-operation, engagement, and the development of problem-solving strategies” (Gros, 2007), as well as promoting collaborative work among players (Baek, 2010).

The disadvantages of the use of educational games should be considered to improve their development and implementation. The main one is the cost (Torrente *et al.*, 2010), as educational games designed until 2005 were expected to cost more than 100 thousand dollars (Michael and Chen, 2006). Nowadays, the costs have been reduced, but well-designed educational games might require a large team of developers and educators, which may raise the games' retail prices. Other concerns involve the fact the adoption of games by the learner takes time and requires orientation as the educator has to explain how the game works (Tüzün *et al.*, 2008), and learners may perform off-target activities while attracted and distracted by the game environment (Bakar, Inal and Cagiltay, 2006; Tüzün *et al.*, 2008).

The implementation of games in the classroom must consider the fundamental role teacher plays on classroom interventions and technology adoption (Magliaro and Ezeife, 2008; Aremu, 2010). As stated by Kenny & McDaniel (2011), classroom interventions may be successfully adopted when teachers believe that the experience is worth the effort. The adoption of a particular educational strategy is related to teacher's views, ideas and expectations, so "if a teacher sees little or no value in an intervention, or is unfamiliar with its use, then the chances that it will be properly implemented are minimised" (Kenny and McDaniel, 2011, p. 199). Considering this, researchers have worked on questionnaires to comprehend what teachers think about the use of games for education and which challenges they face while implementing those in the classroom. Through a questionnaire applied to almost 500 Korean teachers, Baek (2008) identified six main factors that inhibit them from using videogames to support education: the inflexibility of the curriculum, adverse effects of gaming, students' lack of readiness, lack of supporting materials, fixed class schedules, and limited budgets. A research conducted by the Joan Ganz Cooney Center resulted in a survey answered by 505 teachers from the United States, showing that cost, lack of technology

resources, and emphasis on standardized tests are barriers that hinder teachers from using classroom games (Millstone, 2012). In Europe, Wastiau, Kearney, & Van den Berghe (2009) made a study with 528 teachers from 27 countries. Although 70.6% of the respondents use games at school, they state that obstacles such as cost and licensing of the videogames, the timetable of the school, and the difficulty in finding suitable games make the implementation harder. This necessity of finding appropriate games for teaching is in line with a more recent study with science teachers published by Sánchez-Mena, Martí-Parreño, & Aldás-Manzano, (2018), which shows that usefulness is a predictor factor for teachers to adopt games in the classroom. According to the authors, a teacher believes that a game is useful when it enhances their job, improving students learning – 41% of the 111 participants of this study said educational games should be proven to be effective through methods like research studies. Since not every game will be adequate to every context, it is necessary to comprehend how different types of games work, aligning game taxonomies and learning taxonomies (Van Eck, 2006).

In early childhood, the use of digital media and games often plays a key role at home (Nolan and McBride, 2014). However, there is evidence that, when implemented in the classroom, DGBL improves young children abilities such as motor skills (Lestari and Ratnaningsih, 2016), language learning (Meyer, 2012), literacy (Rambli, Matcha and Sulaiman, 2013; Ronimus *et al.*, 2014) and mathematics (Sudarmilah *et al.*, 2013; Dillon *et al.*, 2017). Developing games for this age group involves multiple challenges but especially being aware of their developmental level of learning, including cognitive, emotional, and psychomotor developments (Peirce, 2013). When entering primary school, students face a lot of changes. In many countries, while preschool is optional, it is compulsory to attend the primary school level. While preschool focuses on playing and child-centred methods, the

primary school focuses on subjects and lessons (Einarsdottir, 2006). Some researchers evaluate ways of rescuing the play-centred strategy of teaching and demonstrate that DGBL in primary school can efficiently improve the learning outcomes. This can be identified in the learning process of subjects like geography (Tüzün *et al.*, 2009), mathematics (Robertson and Miller, 2009; Brezovszky *et al.*, 2019); language learning (Nazleen, Rabu and Talib, 2015), science (Hussein *et al.*, 2019), besides skills like creativity (Wu *et al.*, 2012) and computational thinking (Tsarava *et al.*, 2017).

According to Romero (2019), DGBL in secondary school tends to include four main ways of learning: through entertaining games that are adapted to the educational environment; through games designed to be educative; by adopting games mechanisms to frame educational activities; and by letting students develop and create games. Learning through digital games is not limited to school learning – higher education is also target as a subject of research in the area. Research has proven the power of DGBL for secondary school education when applied to mathematics (Vankúš, 2008), science (Khan, Ahmad and Malik, 2017), genetics (Annetta *et al.*, 2009), and physics (Zuiker and Anderson, 2019).

When developing games for students in higher education, it is essential to consider how adults learn. Adults need to know what they will learn before starting it, to be in charge of their learning, to feel able to apply their skills to solve real problems and to learn through a task-focused process (Knowles, Holton and Swanson, 2005). While some children might be motivated to learn just because they are playing a game, adults tend to perceive game-based learning as a time-wasting activity. Therefore, educational games designed for higher education should make clear to the player what are the benefits of playing, and communicate the learning outcomes (Whitton, 2009).

2.1.2 Focus in primary school

This research focuses on the aspects related to the use of digital educational games for primary school mathematics learning. The references that will guide the reader to the problem statement and proposed solutions focus on the challenges of designing videogames for primary school pupils. Primary school education provides fundamental skills that will be quite important for students' future learning. When a student fails to acquire these skills in primary education, the secondary level will be challenging to pursue because of those previous gaps (Connolly *et al.*, 2010). Information and communication technologies have been included as a tool that supports teaching in primary schools, like laptops, interactive white-boards, the internet and educational games (Miller and Robertson, 2010). Previously, computers were used at schools only as a tool for information and communication technologies classes and did not make part of other subjects' courses such as science, mathematics and social studies. Now, computers are integrated into the learning process of a variety of topics and allow interactive learning, improve problem-solving skills and provides feedback on students' performance (Seyda Gul. and Yesilyurt, 2015). Furthermore, information and technologies skills are now part of the eight competencies for lifelong learning strategies proposed by the European Commission (Commission, 2018).

Even though the use of technology for learning is an explored field, more information about how to implement videogames in the classroom is needed, especially for primary school learning. In a review of 105 empirical studies about the use of videogames for primary school, Hailey, Connolly, Boyle, Wilson, & Razak (2016) shed light on few characteristics of the existing games developed to this audience. They argued that most of the effects outcomes from primary school games are knowledge acquisition and content

understanding, followed by perceptual and affective motivational skills and cognitive skills. They also suggest that there is a lack of studies comparing the effect of game-based learning with traditional approaches for primary school education. Another study that takes into consideration the connection between educational games and school level was conducted by Watson, Yang, & Ruggiero (2013). After interviewing 15 teachers at primary and secondary levels, they suggest that “elementary school teachers viewed challenges of implementing games effectively a less serious barrier than middle/intermediate and high school teachers” (p.237). According to the authors, this happens because younger students tend to have lower expectations of game quality than older students. However, primary school teachers seem to have more difficulty in finding good educational games, then secondary/high school teachers (Watson and Yang, 2016). Therefore, there might be a need of investing in the development of games for this school level, especially considering the needs of reinforcing the learning of concepts that will serve as fundamentals for the knowledge acquisition when the student reaches higher educational levels.

2.1.3 The specific case of mathematics learning

Although educational games can be applied to a wide range of curriculum subjects, this research focuses on the use of videogames for mathematics learning. According to Richard Skemp, a pioneer in mathematics education that first combined the disciplines of mathematics, education and psychology, mathematics should be a tool for improving human thinking. Skemp defines mathematics as a powerful tool and concentrated example of functioning human intelligence, and “one of the most powerful and adaptable mental tools which the intelligence of man has made for his use, collectively over the centuries” (Skemp, 1989, p.26). He compares the development of mathematics with the development of

important tools, like screwdrivers, but consider it a tool designed to increase our power of thinking. Even before school, when they are still very young, children start to have contact and use mathematics to improve their daily life. They learn how to count the number of toys they have, how old they will be on the next birthday, how long it will take to their favourite TV show to start. Some studies show that, from birth to age five, children develop everyday mathematics based on ideas of more or less, shape, location, patterns and size (Baroody *et al.*, 2006; Ginsburg *et al.*, 2006; Clements and Sarama, 2007). According to Ginsburg, Lee, & Boyd (2008), everyday mathematics is not an imposition from adults, who may be ignorant about it, but a natural process of children's cognitive development. After starting the early years of school, children are supposed to learn how to think in a more complex mathematical way. As stated by Skemp (1989), there are times when the learning process during formal education does not result in the acquirement of knowledge of mathematics for life. With reading, for example, there is a continuity in the learning process. Children learn how to read for entertainment, learning and horizons expanding. As adults, they keep using the tool of knowing how to read in the same pattern. With mathematics, things are different: most of the children learn and use it to pass exams, get good marks and make their parents happy. Furthermore, international concerns about mathematics education usually involve factors related to children's poor level of understanding of maths concepts (Conway and Sloane, 2006). This is related to the difficulty of applying what they learn at school as a tool to solve real-world problems, which is a consequence of schools focus on procedural, routine, and inflexible knowledge. In a chapter that critically evaluates projects of popularization and communication of mathematics, Ernest (1996) show that negative myths about this subject are widespread in society – the idea that mathematics is hard and boring, for example. According to him, the source of the mathematics myths is the stereotyped experience of

school learning shared by many. Other studies argue about the concern of students' negative attitudes towards mathematics. One of them, published by Di Martino & Zan (2010), proposed 1,496 students from primary and secondary schools to write an essay with the theme "Me and Maths". The authors highlight that failures and unease characterise many of the stories, and students show a low perceived competence joint to the instrumental vision of mathematics. According to the authors, students' lack of self-confidence is reinforced by repeated experiences perceived as failures, when students feel they do not control their performance in maths and think is useless to work on it. Another interesting result is that a high number of students exhibits a change in their relationship with maths during school life. Students say they used to have a positive relationship with mathematics during primary school, but it became negative in secondary school. The transition of one school level to another is then a critical phase. However, maths anxiety is a condition that can be already identified in primary school children (Ramirez *et al.*, 2013), and its presence is associated with poor mathematics performance at school. Nevertheless, maths anxiety not only brings concerns about performance at school: high level of maths anxiety is related to poor drug dosages by undergraduate nurses (Mcmullan, Jones and Lea, 2012). Therefore, the earlier a student starts to develop a better relationship with mathematics learning, higher are the chances this person will succeed during the coming grades of school or in the future career. 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. A longitudinal study designed and implemented by Siegler *et al.* (2012) presents the relevance of primary school learning. 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 ten 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 mathematics 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. The use of technology for mathematics learning allows students to engage with mathematical knowledge in a way that it is possible to understand how these concepts to solve problems from the real world, giving meaning to the learning process.

While every subject learning process has its challenges, mathematics is, nowadays, a concern as the “traditional approaches of treating math like a cold-blooded subject amid the warm and engaging world of K-12 schooling are a big part of the problem” (Pappano, 2013, p. 10). The solution, proposes Pappano (2013), is to help students to build math identities, changing their relationship with the subject. One of the ways researchers in education believe could change children's connection with mathematics is using technology. When combined with appropriate pedagogy, digital technology may “open up new routes for students to construct and comprehend mathematical knowledge and new approaches to problem-solving” (Bray & Tangney, 2017, p. 270). According to Noss & Hoyles (1996), the use of computers in the classroom opens up pathways for meaningful mathematics. In line with that, Drijvers, Mariotti, Olive, & Sacristán (2010) suggests:

“Technology has, therefore allowed school mathematics to incorporate a more operational focus that adds another dimension to understanding. By an operational focus, we mean an emphasis on the practice and applications of mathematics through visualization, manipulation, modelling, and the use of mathematics in complex situations.”

(Drijvers, Mariotti, Olive & Sacristán, 2010, p. 139).

Therefore, with technology, learning mathematics seems to start making sense, and the subjects cease to be a collection of unrelated facts and rules that must be learned only to get good marks at school.

Empirical studies have shown that educational games may be an exciting resource to improve mathematics learning, especially for primary school students. In an experiment with 92 students from primary school, Chang, Wu, Weng, & Sung (2012) pointed out that educational games were able to improve skills related to mathematics such as problem-solving and problem-posing when compared to traditional paper-based approaches. Bakker, van den Heuvel-Panhuizen, & Robitzsch (2015) implemented research with 719 primary school students. The results suggested that minigames, when played at home and debriefed at school, promote students' multiplicative operation skills. The successful implementation of educational games for mathematics learning is also efficient for students with learning disabilities. In a study published by De Castro, Bissaco, Panccioni, Rodrigues, & Domingues (2014), 7-10 years old students with a low level of maths knowledge (dyscalculia) performed a mathematics practice through a platform with 18 digital educational games. The reinforcement of mathematics concepts was significantly higher in the group that played the games when compared to a group of students who learned through traditional classes.

2.2 Situated Learning

Theories of education and teaching approaches underpin well-designed educational games. The range of ideas is broad, and this thesis does not aim to describe all of them. In the present research, the focus will be on the situated learning approach, a cognitive theory that claims effective education requires learning to be embedded in authentic contexts of practice. Gee (2004) states that traditional learning is based on "content fetish": any academic area is composed of facts, so education is based on teaching and testing those facts. However, educational theorists from the beginning of the 20th century brought to the world ideas related to experiential learning, a broad umbrella term used to cover a variety of approaches to learning by doing. During the first half of the 1900s, the Swiss psychologist Jean Piaget started to develop the theory of Constructivism, which states that students construct knowledge out of their previous experiences. To Piaget, children "interpret what they hear in the light of their knowledge and experience" and learning is not just a type of information to be transmitted, but an experience acquired through interaction (Ackermann, 2001). Around the same period, the Soviet psychologist Lev Vygotsky worked on the social development theory, also known as social constructivism. His work stressed the importance of communication and social life in cognition. Both Piaget and Vygotsky believed that children learn through acting in the environment, opposing to traditional ways of viewing the mind as a passive container of knowledge and learning as a process of acquiring facts and information (Vianna and Stetsenko, 2006). Even before Piaget and Vygotsky, the American psychologist John Dewey argued about how children learn better when interacting with their environments. He believed that schools and classrooms should represent real-life situations, where children could participate in learning activities that would be flexible in a variety of

social settings (Dewey, 1938). The concept of learning by doing is continuously attributed to Dewey's ideas. Learning by doing is related to the notion that one learns from his/her actions, rather than listening to others' instructions or lectures (Reese, 2011). This concept was already part of Plato's philosophy, who believed that the nature of philosophy was only learned by those that practised it, not from books that described it (Annas, 1981).

The game designed during this PhD research is based on the pedagogical approach that is intimately related to the idea of learn-by-doing. The Situated Learning approach considers that what is learned is specific to the situation in which is learned (Anderson, Reder and Simon, 1996). Therefore, stimulates learning to happen to solve problems presented inside the context of learning. While traditional learning usually takes place in abstract experiences, such as lectures and books, in situated learning, the knowledge is obtained through contexts that reflect how the concepts can be applied in real-life situations. Traditional education focuses on retention of knowledge, while situated learning focuses on the application of knowledge. (Lave and Wenger, 1991) stated that no activity is not situated. In this case, learning occurs when settings resemble an action, person, time or space. While in the most traditional instructional learning approach the knowledge is acquired for use in a distant future, in the situated learning, what is learned can be implemented into a context or experience lived by the learner. The idea that the context shapes the form of what is learned, being more or less useful depending on the situation, leads to the idea that learning should be taken in contexts that reflect real situations replicated inside or outside formal environments such as the classroom (Waite and Pratt, 2011).

2.2.1 Applications

Several attempts have been made to find tools that allow education based on the situated learning guidelines, especially in the higher education classroom. Chiou (2020) adopted 3D virtual reality to teach higher education students from a course in children development assessment. Compared to traditional methods of learning, like pencil and paper learning, the model proved to be more efficient as students that used the virtual reality tool scored higher points on the post-test. A situated learning program for pre-service teachers to learn how to adopt technology in the classroom, which resulted in participants successfully adopting technology during their teaching practice (Bell, Maeng and Binns, 2013). In a large-scale study with 1000 middle school students, Dede *et al.* (2005) used a digital simulated 19th-century city where students had to solve problems related to the illness by interacting with each other and using digital artefacts. When compared to those learning through paper-based education, students who used the situated learning simulation had a high improve on their biological knowledge, and several them reported to have enjoyed science class for the first time. Although research shows that situated learning can be a beneficial teaching approach, there are some challenges behind adopting it, especially in formal education. While debating about situated learning and computer science course, Ben-ari (2010) criticizes some of the issues with the adoption of this teaching method. The researcher says that, while situated learning recommends that teaching happens in real-life situation, it is not always possible to guarantee student will learn inside this type of environment for every field of learning.

In mathematics, one of the first attempts to adopt situated learning was reported by Carraher, Carraher and Schliemann in 1985. They had as subject young people that worked

alone or with their families selling products in the streets of a Brazilian city. They performed informal mathematics tests related to the products they sell (for example, they were asked the price of coconut and how much would cost if a customer wanted to buy 10 of those). Later, the young sellers answered formal maths tests, like the ones traditionally implemented in classrooms. They performed significantly better on the informal test than on the context-free standard test. Studies about situated learning continued with the anthropologist Jean Lave, who investigated how people used arithmetic out of school in daily life, checking how mathematics is implemented in situations like going to the supermarket and cooking (Lave and Wenger, 1991). The situated learning approach can be used to teach different topics and subjects. When learning how to talk, children do not memorize words from the dictionary. Acquiring a first language is an impressive intellectual achievement people perform, and it happens naturally when others - in the beginning, the parents – apply the words in a particular context so that children can comprehend their meanings (Miller and Gildea, 1987).

The level of tightness of the learning to the context depends on the type of knowledge that is being acquired (Anderson, Reder and Simon, 1996). One challenge related to the use of situated learning as a teaching approach is to give the learner the ability to extend that knowledge to other contexts. For example, if a student understands how to use fractions to divide a pizza properly so everybody in his group of friends can have a slice, s/he should also be able to use fractions to count money or measure time.

2.2.2 Design principles

When designed considering the possibility of situated learning, educational games are useful as learning takes place inside a meaningful context (Lo *et al.*, 2008). For example, if somebody plays *Super Mario Bros* for the first time, s/he might not know that this is a

game where the player runs and jumps across platforms and atop enemies in themed levels. However, there is a component of trial and error that leads the player to succeed: one realises that pressing a specific button allows the character to jump over an empty abyss and that the adorable turtle might not be the best friend as the player dies after touching it. These trial and error situations are opportunities to learn and apply the knowledge to win the game. In videogames, the content taught to the player or that the player needs to know to progress is often situated within the same context in which it will be required and useful.

Gee (2003) argues that learning involves a lot of “playing a character”, so students might learn science while thinking, acting and valuing as a scientist, for example. According to Gee, “videogames are particularly good examples of how learning and thinking work in any semiotic domain when they are powerful and effective, not passive and inert” (Gee, 2003, p.81). Squire (p.19, 2006) argues that games are designed experiences that allow players to learn "through a grammar of doing and being". The author looks at games as opportunities of situated learning, where one learns through doing.

Video games offer an opportunity of implementing situated learning strategies. The interactive nature, the flexibility of adapting the environment, and the chance to have a student playing a particular role while immersed in a context that simulates real-world situation allow games to be in line with the design principles of situated learning environments. According to Herrington and Oliver (1995), situated learning multimedia should provide, among others, a context that reflects how knowledge is used in real life; multiple roles and perspectives; integrated assessment of learning within the tasks; and coaching and scaffolding at critical times. Situated learning principles are distributed among

the main three elements of this learning process: the learner, the implementation, and the interactive multimedia program (IMM program). Figure 2 presents this framework in detail:

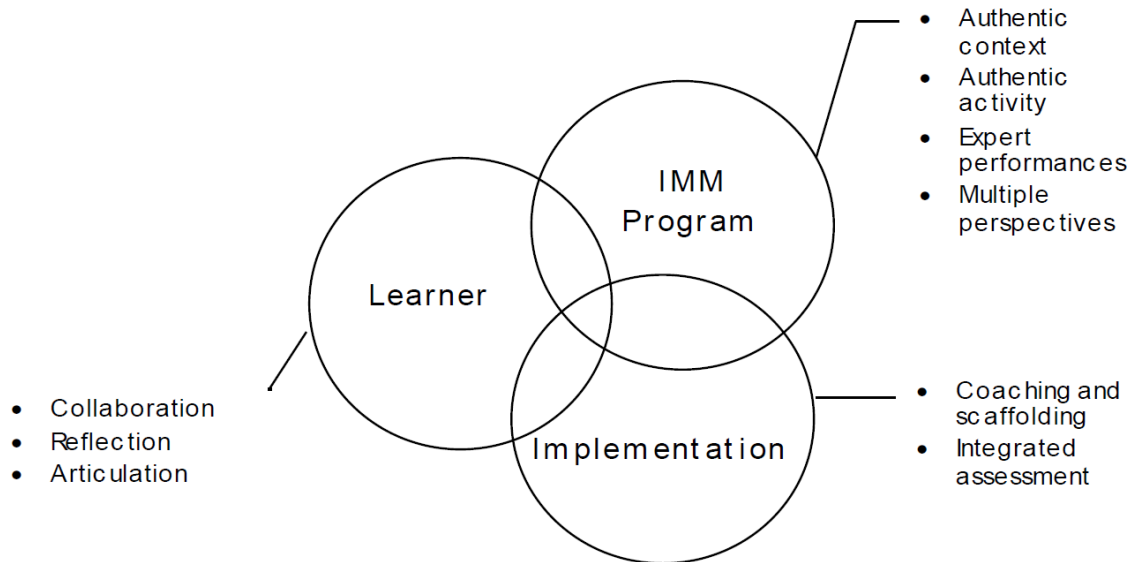


FIGURE 3 ELEMENTS OF SITUATED LEARNING DESIGN OF MULTIMEDIA (HERRINGTON AND OLIVER, 1995)

In situated learning, the situation (also referred to as the context) can be given by a specific narrative or story, illustrating a type of situated learning called narrative-based learning. Narrative-based learning environments provide a contextualized way of learning, making the process more engaging and effective (Mcquiggan *et al.*, 2008). When applied to DGBL, narrative-based learning can result in games with characters that are independent, highly affective, and that builds an empathetic relationship with the player. One example is FearNot!, a character-driven computer game that focuses on anti-bullying social education (Watson *et al.*, 2007). For subjects like science and mathematics, narrative-based learning leads students to connect the concepts learned to the human experience (Hobbs and Davis, 2012), which can result in making abstract concepts more meaningful.

2.2.3 Digital Game-Based Situated Learning

In 1975, the Hungarian psychologist Mihaly Csikszentmihalyi published a study describing his experience in observing a variety of people engaged in activities such as chess-playing, music composition and basketball playing. Csikszentmihalyi identified that, when those people were fully involved in the activity, they reached a state called flow, leading to an experience of powerful motivation and satisfaction (Csikszentmihalyi, 2000). The flow plays a significant role in game development – understanding what makes players engaged is one of the most critical aspects of game design (Jegers, 2007). Integrating a situated learning approach to DGBL gives the opportunity of behaviours of flow, which can lead to a higher engagement and, consequently, improving the outcomes of the learning process (Hou, 2015). Although flow is considered to play a critical role on learning through playing games, researchers suggest the term more appropriate to define the experience of playing a game (Brown and Cairns, 2004; Ermi and Mäyrä, 2005; Jennett *et al.*, 2008). Therefore, immersion is how the specific psychological experience of playing and engaging with a digital game is called (Jennett *et al.*, 2008), and this experience is a relevant element on the process of learning (Cheng, She and Annetta, 2015).

2.2.3.1 Problem-solving in digital games

Several research papers report that the adoption of DGBL promotes the development of problem-solving abilities, which is one of the 21st-century skills (Chuang and Chen, 2007; Sánchez and Olivares, 2011; Lay and Osman, 2018; Pratama and Setyaningrum, 2018). A model developed by Eseryel *et al.* (2014) attempts to explain why learning through games is connected to problem-solving skills development. When playing video games, learners tend to get motivated, leading to a state of engagement during the gameplay, which results in

developing problem-solving abilities. Nevertheless, this always depend on the design of the game, which should be motivating enough to keep students engaged on the challenges they are solving. In an analysis of problem-solving styles, Hamlen (2017) compared how people solve problems in real-life and in video games. The author evaluated 138 surveys answered by undergraduate college students. The results suggest that, people who prefer using organization and structure to solve problems, for example, tend to use the same strategy while solving video game challenges. This support the fact that videogames might support developing problem-solving skills that can be applied on real-life.

2.2.3.2 Irish education

To better present the progress of this research, it is essential to illustrate the environment that inspired the development of this game: the Irish primary schools. In Ireland, the primary school mathematics curriculum comprises five strands: number, algebra, shape and space, measures, and data. The document provided by the government to describe the maths curriculum highlights the importance of teaching these different areas as interrelated units. This strategy would show to the students that one depends on the other and that, “while number is essential as the medium for mathematical calculation, the other strands should receive a corresponding degree of emphasis” (p.3, Government of Ireland, 1999). This document also highlights the importance of technology for teaching maths in the classroom. When giving examples of how to adopt Information and Communications Technology (ICT) at the school environment, the document states that adventure-type programs that require students to solve specific mathematical problems in a meaningful context “offer opportunities for the development of problem-solving skills” (p.8, Government of Ireland,

1999). Therefore, the Irish curriculum seems to stimulate educators to teach maths as a tool to solve daily life problems.

When the topic is maths performance, Irish students have good results on standardised tests. According to a report launched in 2015, Irish primary school are ranked ahead high-achieving countries such as Finland (Mullis *et al.*, 2015). However, the outcomes are different when their problem-solving skills are tested. A national assessment conducted by the Educational Research Centre with over 8,000 pupils showed that children from second and sixth classes scored, correctly, 54% and 49% of the problem-solving questions (Kavanagh *et al.*, 2015). Therefore, there is still room for further development in problem-solving training for the primary school level in Ireland, especially considering that the skills acquired during this educational level are essential to the following years. In Ireland, most of the primary school children are between 6 and 12 years old. A study entitled Growing Up in Ireland was designed to follow how the performance and attitudes of 9 years-old students influenced their results and skills when they started the secondary school at the age of 13 years old (Smyth, 2017). Low mathematics test scores and negative attitudes to Maths learning in the age of 9 years old have a strong influence on how children performed and engaged with maths education at the age of 13.

The necessity of supporting students to develop their problem-solving skills is already being considered in the development process of a new Irish primary school curriculum. The last revised curriculum for Irish primary schools was introduced in 1999, incorporating innovative pedagogical practice for those times. Since 2016, the National Council for Curriculum and Assessment (NCCA) have been reviewing and redeveloping this curriculum, working together with educators and researchers to adapt it to the changes Ireland

went through the last 20 years. In February 2020, NCCA launched a draft version of the new curriculum so parents and educators could give their opinions about it through a questionnaire. The new curriculum comprises seven key competencies, such as "Being Mathematical" and "Being a digital learner" (NCCA, 2020). According to the document, being mathematical means "children drawing on a range of knowledge, skills, concepts, attitudes, values and dispositions as they recognise, interpret and apply real-world information presented mathematically" (p. 8, NCCA, 2020). This competency would allow children to recognise the importance of mathematical knowledge in their daily lives. As the Irish curriculum dates from the beginning of the century, there is not much emphasis on the importance of ICT for maths teaching. However, supplementary documents were developed to support educators in the adoption of those tools. In 2008, there was an investment of €252m in ICT by the Irish government to integrate technology into teaching across the curriculum (Eivers, 2019). Later, policy documents were launched, such as the Digital Strategy for Schools 2015-2020 (Department of Education and Skills, 2015). The report brings information about how stakeholders can integrate ICT into teaching, learning, and assessment practices. Although strategies are being defined to improve hardware acquisition by the Irish classrooms, the deficit in the availability of proper educational software can be a barrier. In a study made in 2015, 44% of Irish pupils were in schools where the principal believed that lack of software for maths instruction hampered instruction (Mullis *et al.*, 2015).

Another factor that should be considered when we try to have an overview of the educational system of a country is to look at students' attitudes towards mathematics. However, there is not enough information about how Irish primary school students feel about

maths. Most of the research about students' perception of maths focuses on secondary school students. One of them is a study with 356 students with age between 15 and 18 years old evaluated their attitudes towards mathematics. 72.8% of them confirmed that past experiences influence their interest or disinterest in maths, and twice as many students expressed a disinterest than an interest. 33.1% of the students said they do not use maths outside the school, showing they are not aware of the utility of this subject in everyday life (Lane, Stynes and O'Donoghue, 2014).

Standardised tests also influence how students in Ireland feel about mathematics. These tests are administered, scored, and interpreted according to a set of rules. Irish primary schools are required to administer standardised tests in English reading and maths in second, fourth and sixth classes, and to report the aggregated results to their Boards of Management and the Department of Education and Skills. In 2019, researchers showed that three out of four primary teachers agree that primary school pupils get anxious about standardised tests. The study collected the opinions of 1,500 primary school teachers (O'Leary *et al.*, 2019).

A large portion of this thesis was written during the new Coronavirus (COVID-19) spread. Schools and colleges in Ireland remained closed for an extended period, and teachers found themselves having to work hard to identify tools that could be their students learning while outside of school. The quickest solution was to make use of the online environment. However, although there are many teaching tools available, our society is still getting used to the idea of learning online, especially for older generations. More and more, children quickly learn how to interact with the online environment, but not all educational tools keep them engaged as social media and entertainment games can do.

2.2.3.3 Applications in mathematics and challenges

Although DGBL has proven to be an efficient tool for mathematics learning, several educational games do not use all the possibilities the gameplay offers. As stated by Lowrie & Jorgensen (2015), “some of these best design features of games are not being used to promote higher-order thinking and deep learning, but rather visually appealing drill and practice games” (p.5). Many of the maths games available for classroom implementation reproduce pedagogical approaches that are already offered by traditional methods and do not implement innovative ways of playing. According to Devlin (2011), videogames are not supposed to work in the same way as paper-and-pencils exercises as games are imaginary world meant to be lived in and experienced. Even games that claim to develop deep conceptual thinking are usually doing little more than “providing an opportunity to practice basic skills” (Devlin, 2011, p.4). In mathematics, practising is essential to improve skills and competencies. Núñez Castellar et al. (2015) indicated that, compared to paper exercises, drill exercises games improve not only enjoyment but also working memory capacity. Even though, it is not clear how this learning remains through the time and if students can adapt and apply this knowledge to a real-world context, especially considering that, in drill and practice, “once learned, habits are persistent and have low adaptability” (Skemp, 1989). Furthermore, mathematics drill and practice usually leads to inert routine skills and repetition instead of flexible and reflexive learning (Lehtinen *et al.*, 2017).

In primary school, many of the games and educational software are drill and practice type (Smarkola, 2008; Inan *et al.*, 2010). However, a study published by Kuiper & de Pater-Sneep (2014) showed that students might not appreciate this use of technology. The researchers applied questionnaires and interviewed 329 students from fifth and sixth grades from a Dutch primary school to understand what they think about mathematics drill and

practice software. Most of the participants said they preferred and felt more motivated to do mathematics while working with exercises books than when working with drill and practice software. Among different reasons, students selected the exercise book because they could skip an exercise when they did not know the answer and go back in case they wanted to check what they did wrong in other exercises. One of the students said: "the computer doesn't know which sums I find difficult and I want to practice those sums", showing the importance of adaptability as a feature of mathematics education software.

2.3 Learning through a historical perspective

Considering the power of situated learning, researchers and educators have been looking for ways of developing the context that will make knowledge meaningful to the students. One strategy is to teach through a historical perspective: pupils learn the subject while listening how that body of knowledge was developed in our society, considering the type of problems ancient people were trying to solve and even the cultural context of those times. Stories are considered engaging and easier to remember, besides giving context to what is learned and promoting learning via multiple connectivity and retrieval pathways (Neuwirth, Dacius Jr and Mukherji, 2018).

2.3.1 Implementations in the classroom

One way of designing narrative-based learning tools is by using the history of the taught subject. Mamlok-Naaman *et al.* (2004) describe how the use of a historical perspective to teach science to high school students made the class more engaging and resulted in a better understanding of scientific thinking. Mihas and Andreadis (2005) showed the power of teaching the linear propagation of light to fifth grade based on the history of Ancient Greece. In higher education, Bloom and Solotko (2005) describe the potential of teaching about

account books by telling their history and how they were created during the 18th and 19th centuries, motivating students from the accounting courses. These examples illustrate that teaching through a historical approach is not a new strategy, and there is evidence that this method not only motivates students to learn but make them aware that certain body of knowledges are being built since ancient times (Blonder and Mamlok-Naaman, 2019).

2.3.2 Application in digital games

An important element of historical approach-based learning is the immersive feature of learning through a narrative. Children tend to learn better when immersed in a story (Manwell and Sullivan, 2013), and games are a key tool to provide this immersive feeling. An engaging narrative is one of the elements that can make a game immersive, especially when it shows just what is needed at a given time, without presenting all possible characteristics of the game at once (Mendonça, Mustaro and Mackenzie, 2012).

Research on games as an educational tool for teaching history is well documented (Squire, Barab and Technology, 1991; Hasibuan *et al.*, 2011). However, there are not much evidence of multimedia being designed to teach other subjects such as science, mathematics, or physics, through a historical approach. One interesting example was developed by Miller *et al.* (2002) and used to teach middle school students about analgesic drugs. The research group used a web-based adventure based on the history of opioids, and empirical research shows students had significant learning gains and engagement. During the development of this work, other digital medias such as websites (Dias *et al.*, 2017) and videoclips (Hong and Chen, 2016) were designed and tested, but none research about classroom videogame that integrates mathematics and history was found. The implementation of videogames with a

historical narrative to support mathematics learning seems to be a field not well explored by researchers.

2.3.3 The specific case of mathematics

One of the advantages of videogames is the possibility of developing an environment where students can practice concepts learned in the classroom while applying these concepts to solve daily life problems. For instance, people use mathematics in a variety of everyday situations, from buying some groceries in the supermarket to setting a GPS system before a long trip. However, some habits became so natural that it is hard to realize how much of mathematics is involved. There was a time, though, when mathematics did not exist as the structured science we know today, and people had to make a big effort to find solutions for daily life problems. This process of developing mathematics is now part of the history of mathematics and can be used as a tool to teach mathematical concepts. According to Karaduman (2010), “historical analysis has been the basis for the theory that mathematics should be related to life situations” (p.2689), as the great civilizations developed this science to solve economic and social problems of their times. Moreover, it is possible to use the history of mathematics as a teaching tool, as it “lets children experience that mathematics is always developing, that it is continuously changing and that they are part of this evolution” (p.19, Kool, 2003). For a student, it is easy to think about mathematics as a given science, structured and ready to be used. However, mathematics was invented and developed to solve needs from daily life, in a time when there were no mathematics books to be consulted, and everything was empirically learned and constructed. Frank Swetz, a noted author and expert on the history of mathematics, highlights the necessity of understanding mathematics based on its origin:

"Unfortunately, it is easy to get into a rut and teach mathematics as a collection of symbols and procedures designed to produce answers for a given set of problems without really teaching 'about mathematics': where it comes from, how it was laboured on, and how its theories were refined and developed – in brief, its social and human relevance."

(Swetz, 1993, p.1).

The idea of using the history of mathematics for teaching was already present in the 19th century. In 1899, the Italian historian Gino Loria already advocated the use of history in mathematics education, indicating teachers should use it to revisit elementary concepts. At the beginning of the 20th century, Barwell (1913) describes how he introduced some mathematics history while teaching students in Ireland and how it was able to stimulate pupils' interest in the subject. To prove his point, the author threw the rhetorical question: "Does not even a rock appeal more to our imagination when we realize that it has a story?" (p.72). According to contemporary studies, he was right. In an experiment with primary school students, Kool (2003) presented maths challenges from the 16th century and discussed the solutions with the children. Although the experiment was carried out with only one classroom, the researcher presents results that show how children were excited about the activity. According to Clark, Kjeldsen, Schorcht, & Tzanakis (2016), putting together mathematics products and the process of producing mathematics knowledge help students to realize that mathematics results of a contribution from different cultures, is in contact with other disciplines, undergone through changes over time, and stimulates scientific, technical, artist and social development. Other researchers consider using history as a tool to teach mathematics may motivate students while sustaining their interests and excitement (Farmaki

and Paschos, 2007). Moreover, a historical approach humanizes mathematics, making it less frightening, and students may find comfort in knowing that complex concepts took thousands of years to shape into their final form (e.g. Bakker & Gravemeijer, 2006). Today, the use of history to teach mathematics is part of initiatives from established organizations. It is subject of conferences, papers and international discussions (Fried, 2001), such the History and Pedagogy of Mathematics, a study group affiliated to the International Commission on Mathematical Instruction (ICMI) created in the 1970s. Although the literature suggests that the integration of history in mathematics education has many advantages, teachers face some challenges while implementing this in their classroom. The classroom time is already limited to the curriculum coverage, and the addition of the history of mathematics may be time-consuming; and there is also a lack of resource as teachers find it hard to locate material about this topic (Dejić & Mihajlović, 2014).

2.4 Summary and gaps in the literature

The literature review described the potential of digital games for education, both in formal and informal learning. Considering that mathematics is the focus of this thesis, it was demonstrated that digital games improve not only students' performance but also their motivation to learn. However, the previous research also makes clear that not every game can make students learn and enjoy the learning process. In mathematics learning, research suggests that several games available tend to reproduce traditional ways of learning and do not balance the educational elements with the fun side of playing games. When looking deeper at learning approaches, the situated learning strategy seems to be in line with some of the DGBL advocated features: it offers possibilities of learning inside a context, increasing the engagement and enjoyment during the learning process. Considering mathematics is a

subject that many times is seen as challenging and abstract, besides students not being able to see the usefulness of the concepts learned, the adoption of the situated learning approach through a digital game environment seems to be a possibility. This can be done by associating situated DGBL with another teaching strategy: the historical-based approach. This strategy is already adopted in classroom, and research suggest it can bring meaning to abstract concepts and makes mathematics more human and approachable. Humanizing mathematics could, therefore, be a possible way of reducing the anxiety this subject causes to students, increasing their self-confidence and interest to pursue careers related to mathematics in the future.

The challenges of mathematics education, especially in a crucial phase of development like the primary school, are clearly stated by scholars. The adverse effects of mathematics anxiety for children at a young age are also well-documented. Although DGBL has been described as a powerful tool to increase learning performance and reduce general stress, there is not much information on how this could be used for mathematics education at the primary school level. The novelty of the present thesis is to look at the effects of a digital game on mathematics performance and levels of maths anxiety. The game is designed combining situated learning principles and historical-based approach of teaching. Considering the gaps described in the present section, a research question is stated. Both the research question and the research experiments that aim to answer it are described in the following chapter.

3. Research design

3.1 Problem statement and research hypothesis

Digital games may offer the opportunity of learning in a creative space, with possibilities of exploring possibilities of developing problem-solving skills. This will be achieved by the design, implementation and test of a game developed based on pedagogical principles identified in the literature and on games already adopted by teachers.

This PhD focuses on evaluating the effects of a digital mathematics game on maths learning outcomes and levels of maths anxiety. In order to reach this objective, the following research hypothesis is set:

H) A digital game, when developed based on pedagogical principles, can improve students' maths performance and reduce the levels of maths anxiety of primary school students.

The pedagogical principles selected to develop this game are those described in chapter 2, considering the use of a situated learning approach and a history-based game narrative.

3.2 Process of design and development of the game

This chapter describes the steps taken to collect information that supports the design and development of the game tested in the present research. The word “game” will be used to refer to “videogames”. The first steps of game design consisted of the combination of three components: the literature review, the development and implementation of a Preliminary multidimensional self-reporting survey on game-based learning, and the development and

implementation of a Theoretical Game Development Framework (Figure 4). Component 1 was presented in chapter 2, while components 2 and 3 will be presented in the following sections. Designing and implementing these tools, evaluating the results, and selecting principles in line with the development of the game was not the final aim of this research – these are part of the design process. Therefore, all the results of this phase are presented here.

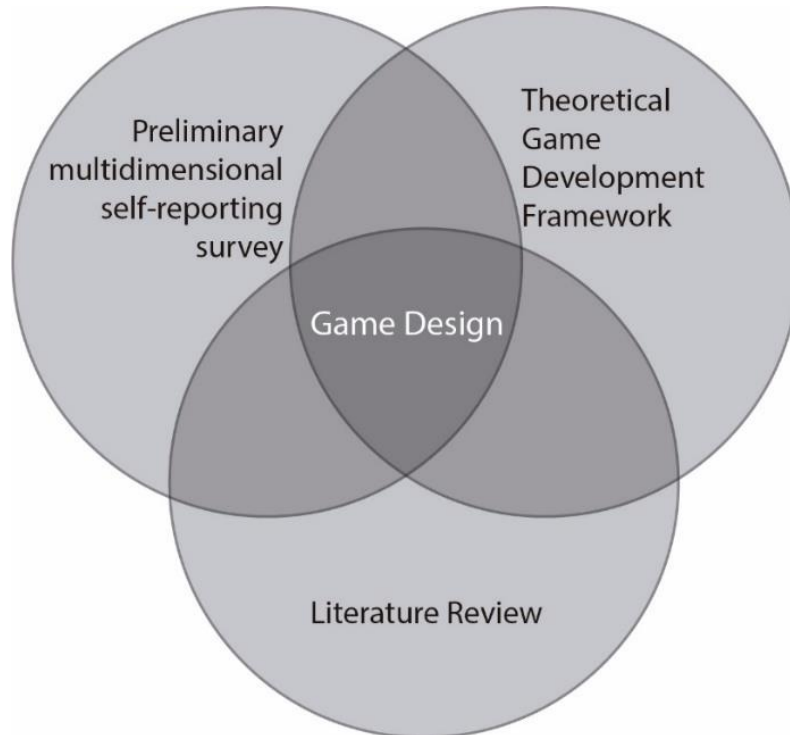


FIGURE 4 THREE COMPONENTS CONSIDERED DURING THE GAME DESIGN PHASE.

3.2.1 Preliminary multidimensional self-reporting survey on game-based learning

The second component of the game design and development is the Preliminary multidimensional self-reporting survey on game-based learning. This consist of a survey answered by teachers considering aspects that concerns the adoption of games in the classroom. Teachers have a key role in the adoption of technology for education, being in

charge of evaluating the available games, selecting those that match teaching aims such as content, pedagogical approach and aspects of schools' routine, such as classes length and available devices. Therefore, when developing a game, one must consider what influence teachers to adopt educational games. The aim of this survey is to identify what are the aspects that influence teachers when adopting games so those can be implemented in the game to be tested in the present research. The survey considers three main blocks of questions based on the previous literature (Wastiau, Kearney and Van den Berghe, 2009; De Grove, Bourgonjon and Van Looy, 2012; Koh *et al.*, 2012; Fishman *et al.*, 2014; Takeuchi and Vaala, 2014). The first block aims to collect demographic information such as respondents' age and gender, what level of education they are teaching, and if the school where they work is on the private or public sector. The second block focuses on the adoption of games in the classroom routine, questioning if the participant adopts games, the frequency of adoption, and what games they adopt games. The third block focuses on teachers' perception of games, considering nine statements about games to be answered with a Likert Scale approach rating from "Strongly disagree" to "Strongly agree", with five levels of agreement. The reliability test shows that these nine statements have a good internal consistency, with a Cronbach's alpha coefficient of 0.77. These statements were collected from previous survey research (Table 1).

| Item | Statement | Reference |
|------|---|--|
| 1 | Games help students to achieve learning goals | (Koh <i>et al.</i> , 2012) |
| 2 | Games improve students' motivation and engagement in learning | (Wastiau, Kearney and Van den Berghe, 2009; De Grove, Bourgonjon and Van Looy, 2012) |
| 3 | Games make it easier to understand how concepts are applied in daily life | (De Grove, Bourgonjon and Van Looy, 2012) |
| 4 | Games improve the interaction between students | (Takeuchi and Vaala, 2014) |
| 5 | There is sufficient time to involve games in classroom routine | (Koh <i>et al.</i> , 2012; Fishman <i>et al.</i> , 2014) |
| 6 | Low costs are involved in using games as a teaching tool | (De Grove, Bourgonjon and Van Looy, 2012; Koh <i>et al.</i> , 2012) |
| 7 | Games cover the curriculum content | (De Grove, Bourgonjon and Van Looy, 2012; Fishman <i>et al.</i> , 2014) |
| 8 | Game design is often too simple and games lack proper pedagogical design | (Koh <i>et al.</i> , 2012) |
| 9 | Games are an easy way of assessing my students' learning | (Fishman <i>et al.</i> , 2014) |

TABLE 1 QUESTIONS INCLUDED MEASURING TEACHERS' PERCEPTIONS OF CLASSROOM GAMES.

Teachers were recruited by convenience through phone calls, e-mail, and social media. The survey was made available in four different languages (English, Italian, Portuguese and Spanish). The versions of the survey can be seen in Appendix 1. The survey collected answers from 714 participants from 34 countries between April 2016 and November 2016. The data was cleaned by excluding responses provided by retired teachers or third level of education lecturers, resulting in a collection of 671 answers. The survey gathered demographic data and teachers' perceptions of games in the classroom.

The questionnaire provided demographic data such as whether the teacher worked in a public or private school, the educational level of their classrooms and the teacher’s age and gender. The primary language of the teacher’s country was classified as English or non-English speaking. The following figure shows the frequency of answers according to each category (Figure 5):

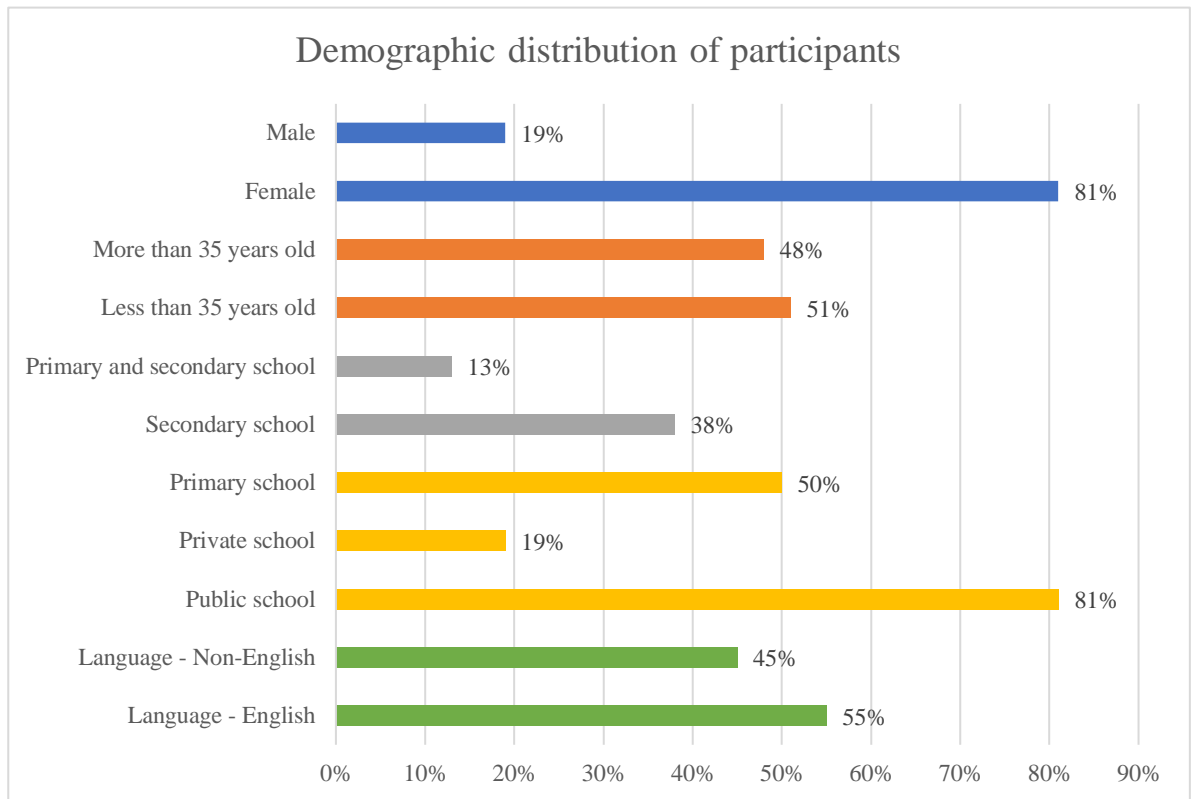


FIGURE 5 DEMOGRAPHIC CATEGORIES OF THE PARTICIPANTS OF THE PRELIMINARY MULTIDIMENSIONAL SELF-REPORTING SURVEY ON GAME-BASED LEARNING

The second block of questions brings information about the frequency of game adoption in the classroom., teachers answered about their use of digital games for education. 60.6% of the respondent teachers use digital games to support education at least once a month, while 39.4% do not use or rarely use games.

The following table describes the descriptive statistics of the level of agreement to the nine statements about DGBL (Table 2):

| Statement | Strongly agree | Agree | Neutral | Disagree | Strongly disagree |
|---|-----------------------|--------------|----------------|-----------------|--------------------------|
| Games help students to achieve learning goals | 47% | 0% | 9% | 44% | 0% |
| Games improve students' motivation and engagement in learning | 64% | 0% | 4% | 32% | 0% |
| Games make it easier to understand how concepts are applied in daily life | 40% | 0% | 15% | 44% | 0% |
| Games improve interaction between students | 58% | 0% | 5% | 36% | 1% |
| There is sufficient time to involve games in classroom routine | 12% | 0% | 20% | 60% | 8% |
| Low costs are involved in using games as a teaching tool | 14% | 0% | 25% | 57% | 4% |
| Games cover the curriculum content | 21% | 0% | 20% | 54% | 5% |
| Game design is often too simple, and they lack proper pedagogical design | 4% | 0% | 30% | 59% | 8% |
| Games are an easy way of assessing my students' learning | 21% | 0% | 21% | 55% | 2% |

TABLE 2 TEACHERS' LEVEL OF AGREEMENT WITH STATEMENTS ABOUT THE USE OF DIGITAL GAMES FOR EDUCATION.

The respondents that do not use games in the classroom were asked to answer why they made this choice. This question generated text-based answers, which were analysed and coded. The results of this analysis are shown in Table 3 and are in line with previous studies

(Koh *et al.*, 2012; Fishman *et al.*, 2014; Takeuchi and Vaala, 2014). Results suggest lack of time (19%), lack of technological resources (19%) and the lack of games appropriate for education (17%) are the main reasons for teachers not implementing games to their classrooms.

| Reason to not use games in the classroom | Answers | Percentage |
|---|----------------|-------------------|
| Lack of time | 25 | 19% |
| Lack of technology resources | 25 | 19% |
| Lack of good games | 22 | 17% |
| Lack of knowledge (about the effects or how to use) | 17 | 13% |
| Games are not useful for teaching | 8 | 6% |
| Too many students | 8 | 6% |
| Do not apply to my case | 6 | 5% |
| Students are not interested | 6 | 5% |
| Lack of school support | 5 | 4% |
| Learning is not about having fun | 3 | 2% |
| Lack of opportunity | 2 | 2% |
| Laziness | 1 | 1% |
| Students already use too much technology at home | 1 | 1% |
| Do not like technology | 1 | 1% |

TABLE 3 REASONS CITED BY RESPONDENTS' TEACHERS FOR NOT USING GAMES IN THE CLASSROOM.

In this self-report survey, teachers also gave information about what games they use in their classrooms. These games were classified according to their language: English, non-English or international (games designed in English and one or more languages). The results

of the primary language of the participant teacher were crossed with the language of the games they use. This was done to check if teachers adopted digital games developed in a language different from the one spoken primarily in the country where they teach. The results show that most of the English-speaking teachers (67%) only use games designed in English. As many teachers cited more than one game, 17% of English speakers said they use International and English games, while 16% only use International games. However, none of them cited a non-English game. Most non-English-speaking teachers, 36%, use international games. 33% of them only use games designed in English, 22% only use games designed in their language; 6% use English and international games; and 3% use a combination of non-English and International games.

The results were evaluated using Logistic Regression as a prediction model to identify aspects that influence teachers to adopt games in their classrooms. Teachers responses were classified according to two groups: those that use digital games at least once a month and those that do not use or rarely use. The logistic regression model was used to predict to which group the teacher belongs, based on the answers each teacher gave to the questions from Block 1 (demographic questions) and Block 3 (perceptions about games; Likert Scale questions), which were adopted as the independent variables. As the difference among cultures may influence practices (Harzing, Reiche and Pudelko, 2013), including the use of games in the classroom, three extra independent variables were included in the analysis. These are the gross domestic product (GDP) of the country the teacher works in; the public spending on education, (i.e. the percentage of the GDP of a country spent on education); and the country's primary language, classified as English and non-English. The multicollinearity of all these factors was tested to check if they were highly correlated, which would mean that two or more different variables were measuring the same feature, leading

to unreliable results in the regression analysis. As the primary language and GDP showed high multicollinearity, the GDP variable was excluded, and only public spending as the economic variable.

The answers to the nine questions (statements) plus the participants' answers to the demographic questions, the public spending with the education of each surveyed country and the primary language of the countries (English/non-English) were selected as independent variables to be used both in the logistic regression model to predict the target variable "use of digital games in the classroom". A multicollinearity diagnosis was applied to guarantee that these factors are reliable. Table 4 shows that the selected predictors have no multicollinearity problems (Tolerance > 0.1 and VIF < 10):

| Variables | Collinearity diagnostics | |
|---|--------------------------|---------|
| | Tolerance | Vif |
| Primary language | 0.70289 | 1.42269 |
| Public or private school | 0.88277 | 1.13279 |
| School level | 0.9147 | 1.09325 |
| Age | 0.90234 | 1.10823 |
| Gender | 0.95969 | 1.04201 |
| Games help students to achieve cognitive learning goals | 0.40323 | 2.47999 |
| Games improve students' motivation and engagement in learning | 0.47035 | 2.12606 |
| Games make it easier to understand how concepts are applied in daily life | 0.51929 | 1.92571 |
| Games improve the interaction between students | 0.60155 | 1.66237 |
| There is sufficient time to involve games in classroom routine | 0.77926 | 1.28327 |
| Low costs are involved in using games as a teaching tool | 0.8715 | 1.14744 |
| Games cover the curriculum content | 0.71284 | 1.40283 |
| Game design is often too simple, and they lack proper pedagogical design | 0.87504 | 1.14281 |
| Games are an easy way of assessing my students' learning | 0.7726 | 1.29434 |

TABLE 4 MULTICOLLINEARITY DIAGNOSIS OF LIKERT SCALE QUESTIONS.

Binary Logistic Regression was performed to assess the impact of the variables on teachers' decision to use games. The model is statistically significant (Chi-square= 119.521, $p < .001$) and explained between 24.6% (Cox and Snell R square) and 33.4% (Nagelkerke R squared) of the variance in the use of digital games status, correctly classifying 72.4% of cases. The result is shown in Table 6, and five variables contribute significantly to the model. The strongest one is the language: teachers from countries that have English as a primary language are 3.7 times more likely to use digital games for education. I also crossed the primary language (English or non-English) of the teacher with the language of the games this teacher uses, classified as English, non-English, or international (games available in multiple languages including English). Looking at the demographic block of questions, respondents who teach to primary school level are around three times more likely to use digital games. The Likert Scale questions showed that teachers who use digital games for educational purposes tend to consider that these tools motivate students (Odds ratio: 2.17; $p < .05$) and can cover the curriculum content (Odds ratio: 1.4; $p < .05$). Those that agree that games for education do not have a good pedagogical design are 0.6 less likely to use digital games in the classroom.

| Variables | B | S.E. | Sig. | Odds ratio | Odds ratio | |
|---|------------|-----------|------|------------|------------|-------|
| | | | | | Lower | Upper |
| Primary language | 1.323 | .281 | .000 | 3.754 | 2.164 | 6.510 |
| Public or private school | .064 | .314 | .838 | 1.066 | .577 | 1.972 |
| Primary school | 1.070 | .367 | .004 | 2.914 | 1.418 | 5.988 |
| Secondary school | -.015 | .358 | .966 | .985 | .488 | 1.986 |
| Teacher's age | .344 | .244 | .159 | 1.411 | .874 | 2.277 |
| Teacher's gender | .036 | .308 | .906 | 1.037 | .567 | 1.897 |
| Games help students to achieve cognitive learning goals | .180 | .257 | .485 | 1.197 | .723 | 1.982 |
| Games improve students' motivation and engagement in learning | .776 | .269 | .004 | 2.173 | 1.284 | 3.679 |
| Games make it easier to understand how concepts are applied in daily life | -.095 | .211 | .653 | .910 | .602 | 1.375 |
| Games improve the interaction between students | -.202 | .207 | .328 | .817 | .545 | 1.225 |
| There is sufficient time to involve games in classroom routine | -.142 | .116 | .219 | .867 | .691 | 1.089 |
| Low costs are involved in using games as a teaching tool | .041 | .117 | .729 | 1.041 | .828 | 1.310 |
| Games cover the curriculum content | .341 | .123 | .006 | 1.407 | 1.105 | 1.791 |
| Game design is often too simple, and they lack proper pedagogical design | -.419 | .132 | .001 | .658 | .508 | .851 |
| Games are an easy way of assessing my students' learning | -.155 | .142 | .275 | .856 | .648 | 1.132 |
| Constant | - 2.929 | 1.17 5 | .013 | .053 | | |

TABLE 5 LOGISTIC REGRESSION PREDICTING THE LIKELIHOOD OF DIGITAL GAME USE IN THE FORMAL ENVIRONMENT.

3.2.2 Theoretical game development framework

The third component of the game design is the Theoretical game development framework, which consists of a system developed to classify classroom games. This step was considered as understanding the features teachers prioritize when adopting games may improve the chances of developing a successful and useful game. In a study of serious games taxonomy, De Lope & Medina-Medina (2017) highlight that it is necessary to control a large number of properties associated with a game to implement it successfully. In the case of educational games, there are also specific aspects to be considered, such as coverage of curriculum content and pedagogical approaches of the game. Therefore, it is essential to look at these games through a classification system that considers their features. Tobias, Fletcher, & Wind (p.498, 2014) say a classification system "organize the knowledge base about game-based learning, identify needed research more effectively, and provide research-based prescriptions for using different types of games".

As shown in Gros (2016)'s review of serious games' design cycle, the existing taxonomies and classification systems developed by researchers classify games according to three main dimensions. The first one considers that games can be classified, giving their target sector or purpose. The sector covers games' categories like the military, government, educational, corporate, advertising, culture, and healthcare (Michael and Chen, 2006; Alvarez and Michaud, 2008). When classified by purpose, serious games are categorized as advergaming, business, exergames, newsgames, activism games, and edumarket games (Bergeron, 2006). The second type includes a combination of these two dimensions, classifying games according to both to the sector and the purpose. The third type of classification considers multiple dimensions. One example is the G/P/S model (Djaouti,

Alvarez and Jessel, 2011) and combines the classification of games based on three different dimensions: the gameplay, the purpose, and the sector. Another classification system embraces some aspects from the educational perspective. Ratan & Ritterfeld (2009) suggest an approach focused on dimensions concerning learning, user, and platform. All these systems could be used to classify a range of serious games, but do not cover all features that may be present and influence the implementation of a classroom game. Although the multi-dimensions systems are more detailed than the others, they still do not bring aspects such as the pedagogical principles of the game, which could be interesting for educators, and technical elements that could be valuable for serious games developers. It is hard to develop one taxonomy that completely covers the plural field of serious games, classifying since games for training employers in a company, and games designed to improve life of people with disabilities, until games used as classroom support. Therefore, specific taxonomies may be useful to cover specific applications of serious play.

To better comprehend which games teachers are using in the classroom, three steps were taken. First, based on previous classification systems and the literature, a Theoretical Game Development Framework was designed. Second, the games adopted by teachers that answered the Preliminary Multidimensional Self-Reporting Survey were organized and cleaned. Third, the Theoretical Game Development Framework was applied to the list of games collected from the questionnaire. This framework classifies videogames considering the specific needs and challenges of the learning experience in the classroom. The elements that compose this system consider as stakeholders educators and researchers in education, although it may also be useful for developers that specifically work with games for classroom learning. This classification system covers three main elements: the Game Pedagogy, the

Game Design and the Game Technical Features. Each aspect contains categories that may include subcategories of classification. Elements of the classroom environment and learning experience connect the three components. The Game Pedagogy section is essential for the analysis of classroom games as its categories evaluate features that affect the learning process such as the pedagogical principle that supports the game, its learning goals, and the assessment of student knowledge. The Game Design section and its categories consider aspects that may influence the gameplay in the classroom, such as the mechanisms of interaction between players and the adaptability of the game to the student's learning pace. Finally, the Game Technical Features element includes categories such as the device used for playing the game, and the type of license, which classifies if it is necessary to pay for playing the game.

This section describes the framework elements and the importance of each category of classification. Some details are highlighted, such as what source should be used to classify the game into a particular category (i.e., by playing the game or checking the game documentation, such as instructions manual or the game website). The system also informs when a game can fall into multiple categories of classification at the same time.

3.2.2.1 Game Pedagogy

Figure 6 shows the categories and subcategories of the framework element *Game Pedagogy*. This element classifies classroom videogames considering pedagogical aspects that may influence the learning process while using games in the classroom.

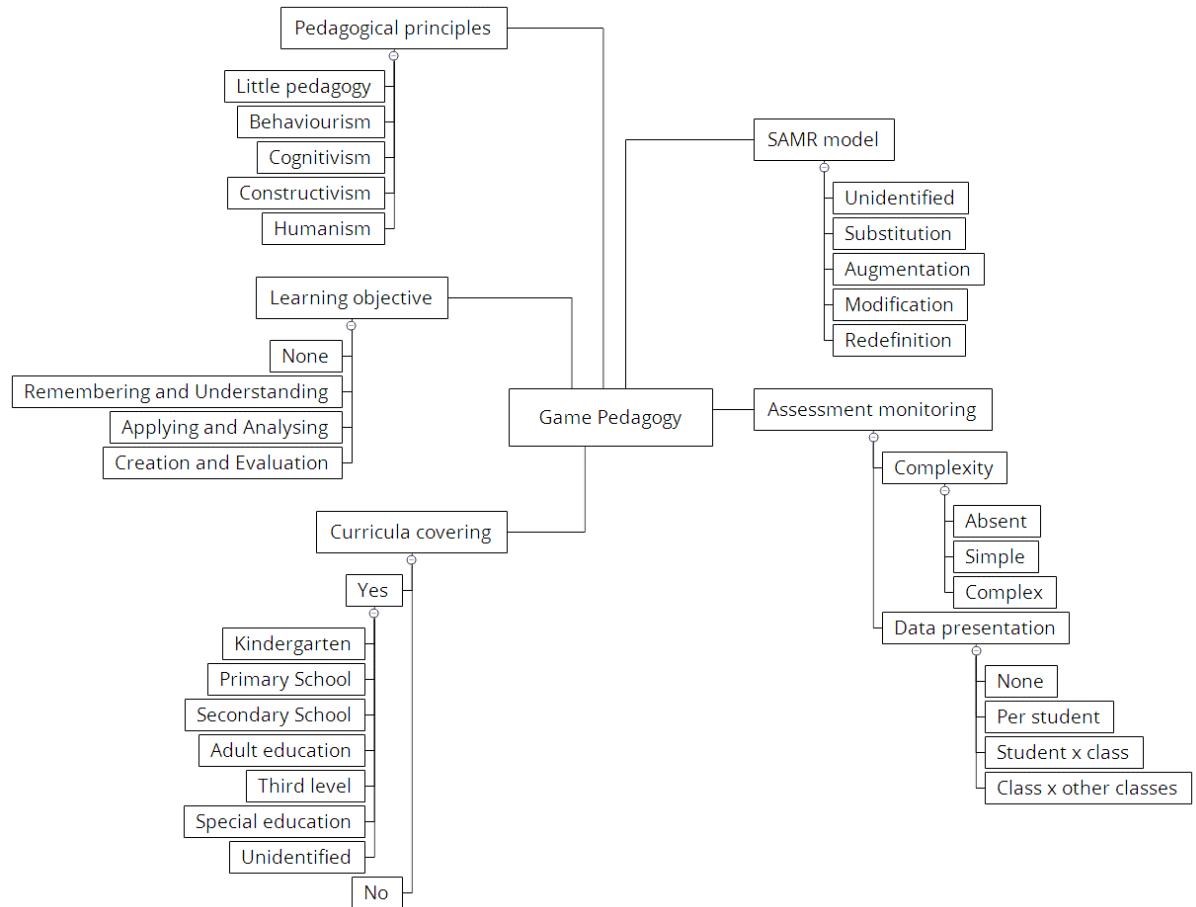


FIGURE 6 THEORETICAL GAME DEVELOPMENT FRAMEWORK – CATEGORIES OF GAME PEDAGOGY ELEMENT

a) Pedagogical Principles

The first category is *Pedagogical Principles* (Patten, Sánchez and Tangney, 2006; Wu *et al.*, 2012). It classifies the videogame considering what, if any, theory of learning underpins it. It is possible to identify this theory while playing the game, although some games may include it in the game documentation. A game can fall into more than one *Pedagogical Principles* subcategories, as it can use different pedagogical theories in different game levels or puzzles. This category is relevant to the analysis because it allows teachers to choose games that follow the pedagogical principle they adopt in their classrooms. According

to an assessment developed by Burgoyne (2003), there are 14 main theories of learning. Four of those theories are key elements that underpin educational games (Wu *et al.*, 2012) and will make part of TCG: *Behaviourism*, *Cognitivism*, *Constructivism* and *Humanism*. I also included the subcategory *Little Pedagogy* to categorize games that have little or none learning theory behind its development. Therefore, *Pedagogical Principles* has five subcategories.

Little Pedagogy is the first subcategory and classifies games with little or no pedagogical principle behind the game design. One example would be commercial off-the-shelf games like Angry Birds (2009) or the Super Mario series (1985). These games are developed to entertain and do not consider learning principles in their development. However, a teacher can choose this type of game and adapt it to support learning in the classroom. It is essential to consider this type of videogame in our taxonomy because it may suggest teachers prefer to adapt commercial games to the classroom or they find there is a lack of specific videogames to teach a particular topic.

The second subcategory is *Behaviourism*. This theory of learning emerged from the work of John B. Watson, who developed, in 1913, a stimulus-response model that states a stimulus from the environment will create a response (behaviour) in an individual. The fundamental principle is to stimulate new behaviour with a reward or discourage it with a punishment. Therefore, Behaviourism understands learners as machines that “could be shaped to respond to conditioning by controlling reinforcements and punishments” (Ang *et al.*, 2008). In a learning videogame, the player can be stimulated with a reward like points or medals when he gives a right answer to a question. When giving a wrong answer, the player may lose points or other rewards, or lose the game and has to start again. The player then learns what should answer when facing a similar situation later in the game. Usually, the

learning process happens when the player carries out repetitive activities – in Behaviourism, the student learns by repetition. Behaviourism is related to a method of instruction known as drill and practice, which consists of a repetition of concepts and practice of problems. According to Lim, Tang, & Kor (2012), drill and practise is a “disciplined and repetitious exercise, used as a mean of teaching and perfecting a skill or procedure”. One example of a Behaviourist game is Math Blaster (1983), where the player has to answer repetitive arithmetic problems and, for each correct answer, earns a bullet. After answering a certain amount of questions, the player can have a break and play an entertaining and non-educational shooting game using the bullets earned. Although launched in 1983, the game is still played nowadays and had new versions launched in 1987 and 1990, both keeping the drill and practice playing style.

In the 1960s, psychologists and educators identified the limitations of Behaviourism as a learning theory, which led to a cognitive revolution. The process of learning was not anymore just a behavioural reaction to a stimulus but a complex process that involves thinking. This revolution resulted in the rise of *Cognitivism*, which is the third subcategory of the *Pedagogical Principles* element. Cognitivism assumes that every person constructs a perspective of the world, which is a mental model for understanding and remembering information (Becker, 2017). Therefore, Cognitivism considers that learning happens by the assimilation and accommodation of this mental model. The assimilation is the process of acquiring knowledge in the mental model, while accommodation is modifying an existing model to accommodate new information (Slussareff *et al.*, 2013). In cognitivist games, the player needs to visit his previous knowledge to identify strategies for winning. While the rules in behaviourist games are understood in the same way by every player, cognitivist

games allow each player to construct their individual understanding of the rules (Ang *et al.*, 2008). This concept is represented by the Lure of the Labyrinth (2009), a game with intriguing mathematics puzzles to be solved by the player. The puzzles do not have obvious solutions, which leads the player to reflect on possible ways to solve it based on his previous knowledge and experience.

While cognitivist games are more complex than behaviourist games, in both types the knowledge is out of the player, and it has to be offered by someone – in this case, by the videogame. However, some games involve problem-solving and insightful thinking in addition to the reward and punishment system. This type of game falls in the *Pedagogical Principles*' fourth subcategory: *Constructivism*. This theory of learning says knowledge happens through interaction while learners are experiencing the world (Ackermann, 2001), so the student plays an active role in the learning process. I use the study of Kebritchi & Hirumi (2008) as a reference to categorize games through this pedagogy. According to them, in Constructivism, knowledge is constructed by the learner. Obikwelu & Read (2012) suggest that constructivist games usually adopt techniques such as the simulation of the real world; the possibility of player comparing his/her problem-solving solution to others'; and peer interaction. The subcategory *Constructivism* includes constructionist games, which focus on learning through making and sharing. The learner is consciously engaged in constructing a public entity, whether it's a sandcastle on the beach or a theory of the universe' (Papert and Harel, 1991). Minecraft is an example of a constructionist game: the player can construct a virtual world without rules to guide or limit the gameplay, and it is possible to share it with other players. Finally, games can be a source for the construction of a knowledge that is not

simply transmitted but obtained because of the interaction with the game (Braghirolli *et al.*, 2016).

The fifth and last subcategory is *Humanism*, which considers learning is not just about the intellect but also educating taking learner's interests, goals, and enthusiasm into account (Sharp, 2012). According to Wu et al. (2012), "it differs from the behaviourist notion of operant conditioning and the cognitivist believe that the discovery of knowledge or construction of meaning is central to learning". The learning process is centred in the student and is personalized, and the game acts as a facilitator. Even the rules are student-centred, meaning the player could set their own rules to win or lose the game. Humanism has a focus on Experiential Learning, which states that "learning is a holistic process of adaptation to the world" (p.194, Kolb & Kolb, 2005) and that the transformation of experience is what generates the knowledge. Kolb (1984) proposes that experiential learning brings a holistic perspective on learning combining experience, perception, cognition and behaviour. Therefore, humanism deals with the learning process, including not only understanding but also affective aspects. One example of humanistic game is Spent (2011), an online game focused on poverty and homelessness. The player must play as someone that only has \$1,000 to live a whole month, having to choose between equally disagreeable options in order to survive and raise a child. There is no clear rules and each choice of the player has consequences – for example, the player must choose if will pay the electricity bill or buy food. The gameplay leads to an involvement as the player experiences the simulation of a challenging life. The learning happens when the player faces a simulated reality that may be far from what s/he lives – however, at no point the game says which choices the player must do, the learning

happens because of living the experience. The game provides data about how much people face the same situational, which leads the player to be emotionally attached to the situation.

The theories of learning have different levels of complexity and comprehend the learning process through different aspects – behaviour, previous knowledge, construction of knowledge, and experience. Therefore, sometimes a game can be humanistic but also include behaviourist aspects – for example, the game *Spent* could contain drill and practice exercise where the player had to answer mathematics questions to calculate the amount of money necessary to survive.

b) Learning Objectives

The second category of *Game Pedagogy* element is *Learning Objectives*. This category was designed based on Bloom's Taxonomy (Bloom *et al.*, 1956), a model developed to classify learning objective through cognitive, affective and sensory domains. Bloom's taxonomy allows educators to assess learning outcomes in a structured manner, besides helping in the preparation of educational materials. The taxonomy was reviewed, and an updated version was launched in 2001 (Anderson & Krathwohl, 2001), "hoping to add relevance for 21st-century students and teachers" (Orey, 2010). The updated Bloom's taxonomy contains six levels of learning objectives, from the simplest to the most complex. The current taxonomy described in this thesis adapted Bloom's model to four levels but kept the idea of growing complexity. The games need to be played or have their documentation checked to be classified. One game may include different learning objectives at different levels. Still, this taxonomy classifies it according to the highest complexity objective – therefore, a game has only one learning objective. This category allows the educator to choose a game that matches his/her goals for the classroom.

The first subcategory is *None* and classifies games that do not have any learning objective behind the gameplay as they are developed only for entertaining, such as World of Warcraft (2004). Although this type of game could be adapted for educational purposes, different learning objectives could be applied depending on how the teacher implements the game in the classroom.

The second subcategory is *Remembering and Understanding*, which classifies games where the objective is to memorize and comprehend facts and ideas. One example is Monkey Tales (2011), a game where the player has access to drill and practice maths games, like shooting the right answer to a problem.

The third subcategory is *Applying and Analysing*, which comprehends applying concepts to solve problems and being able to identify patterns and structures. One example is the game Logical Journey of the Zoombinis (1996), where the player needs to guide blue creatures called Zoombinis that have specific combinations of hair, eyes, and nose colour. The player needs to solve puzzles to allow Zoombinis to move on. The puzzles depend on the characteristics of the Zoombinis – for example, it is necessary to match Zoombinis with the same features to solve a puzzle.

The fourth and last subcategory is *Creation and Evaluation*, which expects the learner to be able to build a structure putting parts together, and judge and compare the value of ideas. It can be exemplified by the game Cargo-bot (2012), a game where the player has to direct a robotic arm to move crates to a designated spot. To do that, the player must use visual pieces to write a program that determines where the robotic arm should go.

c) Curricula covering

Another category present in the Game Pedagogy element is the *Curricula Covering*. It is binary and assigns values of *Yes* or *No*. It identifies if a classroom game was developed considering the official school curriculum. If the game covers the official curriculum, it is possible to classify it according to the schooling level, which contains six categories: *Kindergarten, Primary school, Secondary School, Adult Education, Third Level, Special Education, and Unidentified*. This classification is done by checking the game or the game instructions manual. The same game can cover more than one schooling level. Although some games may include elements that could be adapted to school context, this category only classifies games that are covering the curricula content and do not require the teacher to work on any adaptation. This is important for categorising classroom games as it facilitates recognizing what resources are available for each grade.

d) SAMR Model

This category consists of classifying the level of integration of technology – in our case, videogames – to the teaching process. The SAMR Model, developed by Puentedura (2009), underpins this category. This model has different categories, and the right one can be identified by playing the game. This category determines the role of the game in the learning process. For teachers, it may help to reflect if the game will change the way the learning process happens or if it just substitutes traditional activities. The *SAMR Model* category is divided into five subcategories. The first one is *Unidentified*, and it is used to classify commercial games that are not developed with educational purposes. In those games, it is

hard to identify what is the role of the videogame as there may have different ways of implementing and adapting the game to the classroom. The second subcategory is *Substitution* and classifies games that substitute a traditional method of instruction without promoting any functional change to the teaching process. Games like quizzes that involve multiple-choice questions to be answered by the player are very similar to traditional paper exercises and are classified in this subcategory. The third subcategory is *Augmentation* and classifies games according to the replacement of conventional teaching tools but brings functional improvement to the learning process. One example is the game Immune Attack (Kelly *et al.*, 2007), which stimulates the immune system and the player, represented by a cell, play by following instructions. The player does not make his / her own choices, so the learning process is still similar to an instructional approach, but is improved by the use of a simulation system. The fourth subcategory is *Modification*, which classifies games that brings a significant redesign of the learning experience. It is common in simulation games where the player's decisions determine the success or failure of a business, for example, the game Industry Giant 2, where the player needs to make decisions to develop a business empire (Puentedura, 2009). Finally, the last subcategory is *Redefinition*, which classifies games where the player can create new tasks in a way that s/he could not do before without the game. The use of the game is essential for the learning experience in this case. One example is the CodeCombat Game (2013), which teaches programming languages and fundamentals of computer science. To advance through the game, players must write a code that determines what is going to happen in the narrative.

e) Assessment monitoring

This category classifies games according to how the player's performance is measured and presented to the teacher. *Assessment monitoring* is divided into three subcategories. The first one is *Absent* and classifies games that do not have a system to show teachers how students are progressing. The second one is *Complexity*, which categorizes the game according to the complexity of performance assessment. By its turn, *Complexity* can be *Simple*, when the game only measures player performance considering elements that are part of the game mechanisms, such as playing time, number of trials and player's rewards. The *Complexity* can also be classified as *Combined*. In this case, the game includes not only elements such as rewards and playing time but also aligning the performance with learning outcomes and content achievement, or permitting teacher to assign different game challenges to students according to their performance in the game. The second subcategory is *Data presentation*, which classifies games according to how the game presents the assessment data to the teacher. It can be divided in *None*, which means the game does not report the player's progress; *Per student/Per class*, when the system shows the progress of each student individually or of each class/group of students, not comparing with others; *Student x Class*, when the system compares each student to the whole class; and *Class x Other classes*, when the game can compare the performance of different classes.

3.2.2.2 Game design

The second element of Theoretical Game Development Framework considers aspects from game design and mechanics that may influence the implementation of the game in the classroom. Figure 7 shows the categories and subcategories of the *Game design* element, followed by their descriptions.

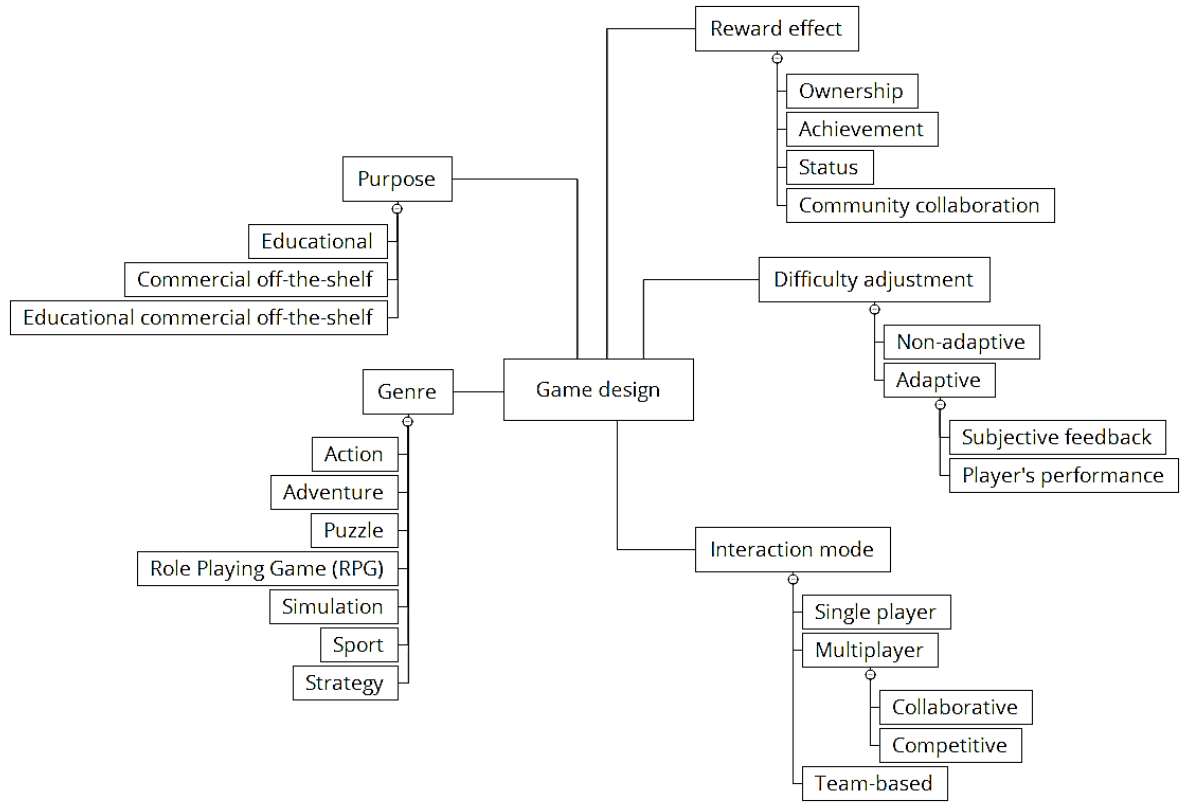


FIGURE 7 THEORETICAL GAME DEVELOPMENT FRAMEWORK – CATEGORIES AND SUBCATEGORIES OF THE GAME DESIGN ELEMENT.

a) Purpose

The first category of the *Game Design* identifies the purpose of the game development. It specifies if a game was designed and developed to be used as an educational tool or if it is an entertaining game that has to be adapted to the learning context. It is possible to classify games according to the *Purpose* by playing the game or consulting the game documentation. A game can only be categorised by one of the subcategories of *Purpose*. The first subcategory is *Educational*, which classifies games explicitly developed as an educational tool, like Mangahigh (2010), a platform of mathematics puzzle games. The second subcategory is *Commercial off-the-shelf*, which includes games designed to entertain

and that does not cover the curriculum content, but can be adapted by the teacher to work as an educational game. One example is Angry Birds (2009), an entertaining game that can be used in the classroom to support Physics learning (Rodrigues and Simeão Carvalho, 2013). The third subcategory is *Educational Commercial off-the-shelf*, and it classifies games that are initially for entertainment but have educational versions launched. One example is Minecraft: Education Edition (2016).

b) Genre

The genre of a game is used to categorize its gameplay characteristics, which is the specific way in which players interact with the game. According to Adams (2010), two games may have the same settings, but, if they have different gameplays, they belong to different genres. The category *Genre* could be identified by playing the game, but most of the times it is described in the manual instructions or other game documentation. This category has eight subcategories (Herz, 1997), and one game can be classified by more than one game genre. When adopting classroom games, teachers may evaluate how a particular game genre will adequate to the content they want the students to learn. The first subcategory is *Action*, which classifies games that have an emphasis on movement. It includes maze games, platform climbing and jumping games (such as jumping over gaps and obstacles), races and chases, as most of the action games test player's physical skills and coordination (Adam, 2010). The second genre is *Fighting*, a type of game that involves two or more characters in a battle with a winner at the end. It may involve two players fighting against each other or one playing against a machine. Differently from action games, fighting games do not include puzzle-solving or exploration. *Adventure* is also a game genre. It is an interactive story about a protagonist character that represents the player. Storytelling and exploration are essential

elements for this type of game, and it involves a lot of puzzle-solving and conceptual challenges (Adams, 2010). The fourth genre of games is *Puzzle*, categorizing games that include problems to be solved. These problems are typically visual and ‘stripped of all story pretence’ (Prensky, 2001, p.20). *Role-playing games (RPGs)* is a genre that classifies a game where the players assume the role of characters and create a narrative together. There are pre-determined rules, but players can make decisions that determine the direction of the story. Most of these games are medieval, and the character may be a human, orc, elf, or wizard. *Simulation* is the sixth genre and is characterised by games that simulate real-world experiences, such as flying, driving or building things. *Sports* is another genre of games, and it is a combination of action and simulation, simulating the practice of different types of sports like baseball, soccer, and basketball. The last genre is *Strategy*. In this type of game, the player oversees a task and should plan strategies to make it evolve (the player can be responsible for a city, for example, and needs to manage it).

It is relevant to state that the genre was identified by considering the features of the gameplay. This should be highlighted because, for some educational games, the gameplay is not related to the learning aspects. One example is the game *Dimension M* (2009), which is an action game where the player needs to find the missing daughter of a scientist. While exploring the scenario, some mathematics questions may appear for the player to answer. If the game is classified only considering the mathematics questions, it would be a *Puzzle* genre. However, most of the gameplay focus on the action, so the game is classified by the *Action* genre.

c) Reward Effect

The *Reward Effect* is the third category and classifies the game according to the effect or meaning its reward system may have in the player (Simões, Redondo and Vilas, 2013). The *Reward effect* can be measured by playing the game, and one game may have more than one *Reward effect*. Rewards play a central role in motivating the player to keep playing and enjoying. *Reward effect* is divided into four subcategories. The first one is *Ownership*, which is the effect of rewards that provokes in the user the feeling of having things, such as points, tokens and badges. The second one is *Achievement*, which is related to the accomplishments of the player, like reaching milestones or completing specific tasks. The third effect is *Status*, which is associated with the competition with other players and can be identified in games with ranks or leaderboards. The last subcategory is entitled *Community collaboration*, and it is specified in games which contains community or group challenges.

d) Difficulty adjustment

This category measures if a game can adapt its content to different players. Players are different from each other and have various paces and styles of gameplay (Charles, Kerr and McNeill, 2005). Some games are designed and developed to adapt elements of the gameplay depending on the user's preferences. This category can be identified through the game's documentation, and, in some cases, by playing the game. One game cannot be assigned to more than one subcategory. Considering our taxonomy focus on classroom games, the fact that students learn in different paces can also influence the way game is used to support learning. Therefore, it is interesting to understand if a game is able or not to adapt its difficulty to students learning process. *Difficulty adjustment* is divided into two subcategories. The first one is *Non-adaptive* and is related to games that use the same

difficulty settings through the gameplay or that adjusts the difficulty based on settings not related to player's performance, like pre-defined intervals of time (Sampayo-Vargas *et al.*, 2013). The second subcategory is *Adaptive*, which is related to games that changes the difficulty according to the player's performance. It is valuable to say that it classifies games that change the gameplay according to players' performance, not considering games that recommend extra practice or gives hints to players that are struggling. It considers two aspects: *Subjective feedback* and *Player's performance*. *Subjective feedback* games adapt the difficulty according to feedbacks provided by the player. One example is described in Shaker, Yannakakis, & Togelius (2010), where a game was automatically adapted after collecting information through a questionnaire where players answered questions about fun, challenge and frustration. *Player's performance* categorizes games where the success or failure of the player in the game is measured objectively. In work from Yin, Luo, Cai, Ong, & Zhong (2015), artificial intelligence is used to capture data about the player's performance and adjusts the game difficulty.

e) Interaction mode

The category *Interaction mode* classifies games considering the way the player interacts with other players. This can be identified by playing the game or checking the game documentation. One game can be classified by more than one subcategory. This category is relevant for classroom games evaluation because of the context of playing. School games are applied to a group of students – the classroom – so their interaction is important to determine the dynamics of the learning process. *Interaction mode* is divided into three subcategories. The first one is the *Single-player*, which classifies games where the player can only play by him/herself, without interacting with others. The second subcategory is *Multi-player*, which

classifies games where more than one player can participate and is divided into two subcategories: *Collaborative*, which considers games where users play helping each other, and *Competitive*, for games where players compete to win. Games can also be *Team-based* when a group of players try to reach a goal to win, playing against other teams.

3.2.2.3 Game Technical Features

The third and last element of the Theoretical Game Development Framework is the *Game Technical Features* (Figure 8). This element considers technical aspects of the game that may influence its implementation in the classroom environment. Our focus is only on parts of the game development that may affect the classroom context – other taxonomies cover features that concerns serious games in general (De Lope and Medina-Medina, 2017).

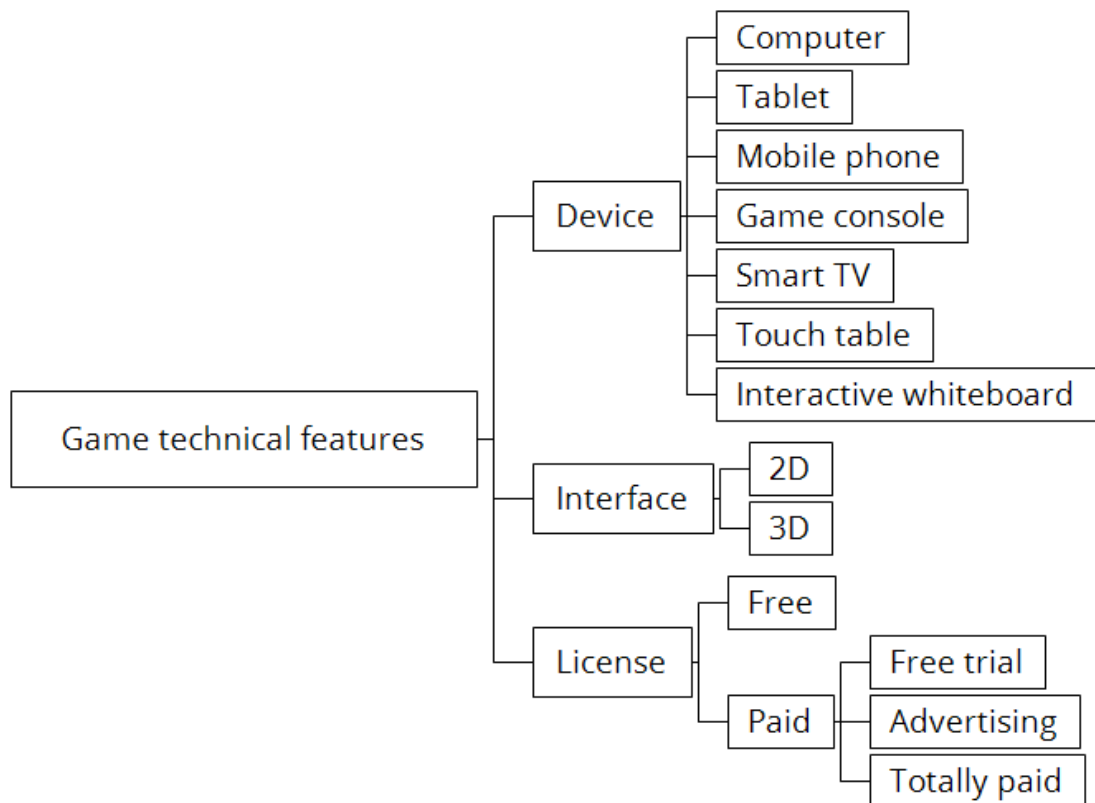


FIGURE 8 THEORETICAL GAME DEVELOPMENT FRAMEWORK: GAME TECHNICAL FEATURES

The first category of *Game Technical Features* element is *Device*, which classifies the platform used to play the game. This can be identified in the game documentation, and the same game can be played in more than one device. This category is divided into *Computer, Tablet, Mobile phone, Smart TV, Touch table, and Interactive whiteboard*. The next category is *Interface*, which classifies how the game is presented. The interface can be two-dimensional (*2D*) or three-dimensional (*3D*), which can be identified by playing the game or consulting the game documentation. One game can have versions in 2D or 3D, so more than one subcategory can be assigned to the same game. The last category is *License*, which specifies the distribution (De Lope and Medina-Medina, 2017). This information can be obtained from the game documentation. This category is important for the teacher, so s/he can know if it is possible to access the entire content of a game without cost. The subcategories are *Free*, for games that can be played without charge, and *Paid*, for games that the user needs to pay to play it. It is important to say that some games may be free in some situations but not in others. For example, *Akinator (2007)* is a game that is free to play in Android system mobile phones but not in the iOS system. I still consider it is a free game because there is a possibility to access it without paying. The subcategory *Paid*, by its turn, is divided into three subcategories. The first is *Free trial*, for games that allow the player to try it before buying. For platform /games website, a free trial happens when the player can access a few games free but must pay to access the full content. The second is *Advertising*, for games that are free to play but present advertising during the gameplay. Only games where the advertising interrupts the gameplay dynamics are classified by this subcategory, excluding games that have an advertisement on their website, for example, but where those ads do not disturb the game. *Totally paid* is another subcategory and classifies games where the player needs to pay to access any part of the content.

3.2.2.4 Theoretical Game Development Framework application

The Theoretical Game Development Framework was applied to classify games used by teachers from primary and secondary schools. The names of the games were collected through the teachers' questionnaire – participants were asked to write down the games used in their classrooms. This generated a list that was evaluated against the taxonomy system described. To clean this list, ambiguous answers that did not uniquely identify a game were excluded, as some teachers wrote, for example, that they use “interactive whiteboard games” but did not provide the name of those games. Answers that cited classic games such as “word search” or “battleship” were also excluded, as these games have many different versions with different level of complexity, and I was not able to identify which one the teacher was referring to. Educational tools that are not games, such as “e-books”, were excluded. User-generated content games, such as Kahoot! (2013) and Quizlet (2007), were also excluded. These games enable educators to create their own quizzes, so the content is generated by the stakeholder. This content can change depending on who creates it, and it would be impossible to cover all the quizzes available in the platforms as the participant teachers did not provide the link to the games they have created. The final list itemized 66 different games to be evaluated against TCG. The list also included websites that work as games platforms – the taxonomy was applied to the games found on those websites.

The first framework element applied to the games is *Game Pedagogy*. This classification was applied to the games adopted by the teachers who answered the survey and the frequency of each element is described in Table 6.

| Game Pedagogy | | | |
|---|-------------------------------|----|-----|
| Category | Subcategory | N | % |
| Pedagogical principles | Behaviourism | 42 | 64% |
| | Little pedagogy | 15 | 23% |
| | Cognitivism | 7 | 11% |
| | Humanism | 3 | 5% |
| | Constructivism | 1 | 2% |
| Learning objective | Remembering and understanding | 39 | 59% |
| | None | 15 | 23% |
| | Applying and analysing | 9 | 14% |
| | Creation and evaluation | 3 | 5% |
| Curricula covering | Yes – Primary school | 38 | 58% |
| | No | 24 | 36% |
| | Yes - Kindergarten | 10 | 15% |
| | Yes - Secondary School | 8 | 12% |
| | Yes - Special education | 1 | 2% |
| | Yes - Adult education | 1 | 2% |
| SMAR Model | Substitution | 42 | 64% |
| | Unidentified | 15 | 23% |
| | Redefinition | 5 | 8% |
| | Augmentation | 2 | 3% |
| | Modification | 2 | 3% |
| Assessment monitoring - Complexity | Absent | 51 | 77% |
| | Combined | 9 | 14% |
| | Simple | 6 | 9% |
| Assessment monitoring - Data presentation | None | 51 | 77% |
| | Per student/Per class | 15 | 23% |
| | Student x Class | 1 | 2% |
| | Class x Other class | 1 | 2% |

TABLE 6 FREQUENCY OF CLASSROOM GAMES CLASSIFIED BY THE ELEMENTS OF THE GAME PEDAGOGY SECTION OF THE FRAMEWORK.

Most of the evaluated games (64%) are underpinned by behaviourism as main pedagogical principal. The literature on the efficacy of behaviourist games is still contradictory. Some argue those games have “limited value for sophisticated knowledge acquisition” (Moreno & Mayer, 2007, p.27) and do not “promote higher-order thinking and deep learning” (Lowrie & Jorgensen, 2015, p.5). Still, Núñez Castellar et al. (2015) indicated that, compared to paper exercises, drill exercises games improve not only enjoyment but also working memory capacity.

Furthermore, the most common learning objective of the classroom games is *Remembering and understanding*, present in 59% of the games. This is in line with the pedagogical principles results, as the behaviourist approach focuses on learning by repetition to memorize the content. It is hard to know if teachers choose to use behaviourist games or if this is the option they have available. By its turn, the *SAMR Model* application is also in line with the idea of applying traditional methods of teaching to a game-based learning classroom. It suggests that most classroom videogames are used just as a substitution of conventional paper and pencil activities (64%).

Our results also suggest that the majority of classroom games cover the curriculum (64%). Previous works have shown that curriculum coverage influences the decision of teachers to adopt games (Sandford *et al.*, 2006; Kim, Park and Baek, 2009; Wastiau, Kearney and Van den Berghe, 2009). The short amount of time teachers has to cover the curriculum content lead them to look for games that are curriculum-related, so less time and effort will be spent trying to fit games to the formal educational environment (De Grove, Bourgonjon and Van Looy, 2012). Our analysis also brought the information that most of the games are designed to cover the content of primary school curricula, and the differences between

primary and secondary school teachers in the adoption of games are not well explored by literature.

Even though games save teachers' time while covering the curricula, this may not happen when considering learning assessment. The assessment monitoring is absent in most of the games (77%), and, when present, usually just show results per student or class, without comparing the data with others.

Table 7 describes the results of the *Game Design* application to 66 classroom games used by primary and secondary school teachers.

| Game Design | | | |
|-----------------------|--------------------------------------|----|-----|
| Category | Subcategory | N | % |
| Purpose | Educational | 51 | 77% |
| | Commercial off-the-shelf | 15 | 23% |
| | Educational Commercial off-the-shelf | 0 | 0% |
| Genre | Puzzle | 48 | 73% |
| | Strategy | 10 | 15% |
| | Simulation | 6 | 9% |
| | Adventure | 4 | 6% |
| | Action | 2 | 3% |
| | Role-Playing Game | 1 | 2% |
| | Sport | 0 | 0% |
| Reward effect | Ownership | 51 | 77% |
| | Achievement | 27 | 41% |
| | Status | 8 | 12% |
| | Community | 1 | 2% |
| Difficulty adjustment | Non-adaptive | 61 | 92% |
| | Adaptive - Player's performance | 5 | 8% |
| | Adaptive - Subjective feedback | 0 | 0% |
| Interaction mode | Single-player | 62 | 94% |
| | Multiplayer - Competitive | 16 | 24% |
| | Multiplayer - Collaborative | 5 | 8% |
| | Team-based | 3 | 5% |

TABLE 7 GAME DESIGN ELEMENT APPLICATION TO CLASSROOM VIDEOGAMES.

The application of *Game Design* element to the classroom games suggests most of them are previously designed with educational purposes (77%). This is in line with the fact that teachers have limited time to cover the curriculum and to work on classroom activities, which make it difficult to them to work on the adaptation of commercial off-the-shelf videogame to the classroom environment. When considering game genres, our study suggests that most of the analysed classroom games are puzzle type (73%), a type of game that, according to Bruckman (1999), is traditionally behaviourist. Many puzzle type games challenge the player through multiple-choice questions, which is very similar to traditional pencil and paper exercises. Moreover, the most identified reward effect, according to our results, is the *Ownership* (77% of games). Most of the evaluated classroom games use points as a reward to the player. Computerized assessment of mathematics concepts has shown that scoring points do not improve the performance of the player (Attali and Arieli-Attali, 2015). However, the literature is still limited and more studies about the role of game reward systems for education have to be delivered.

Moreover, most of the classroom games seem to be non-adaptive (92%), which could be a handy tool considering students may have different ways of learning. Few of the classified games allow multiplayer gameplay: only 8% have a collaborative approach, and 5% include team-based playing. This result may limit the motivation of playing as young players stated a preference for multiplayer rather than single-player games (Kebritchi, Hirumi and Bai, 2010). Researchers recommend a rich interaction among the learner, game, and classroom from the educational game design field (Young *et al.*, 2012).

Table 8 shows the results of the application of the Game Technical Features element to classroom games.

| Game Technical Features | | | |
|--------------------------------|------------------------|----|-----|
| Category | Subcategory | N | % |
| Device | Computer | 57 | 86% |
| | Tablet | 35 | 53% |
| | Mobile phone | 34 | 52% |
| | Videogame console | 5 | 8% |
| | Smart TV | 1 | 2% |
| | Touch table | 0 | 0% |
| | Interactive Whiteboard | 0 | 0% |
| Interface | 2D | 59 | 89% |
| | 3D | 7 | 11% |
| License | Free | 39 | 59% |
| | Paid - Free trial | 14 | 21% |
| | Paid - Totally paid | 13 | 20% |
| | Paid - Advertising | 0 | 0% |

TABLE 8 GAME TECHNICAL FEATURES APPLICATION TO CLASSROOM VIDEOGAMES.

The technical aspects evaluated by this taxonomy consider only features that may influence the implementation of games in the classroom. According to our results, most games can be played on the computer (86%), although a significant amount of games can be played in tablets (53%).

The results also show that most of the games have a 2D interface (89%). Two-dimensional games can be easier to run in cheaper and lower performance device, which can

be the right choice for schools. Finally, 59% of the games are free, and 21% allow a free trial, which minimizes the costs of using games in the classroom.

3.2.3 Practical and technical implementation

After collecting the data from the literature, the teachers' survey, and the classification system, it was time to start the process of game design and developed. A summary of the main aspects of the game designed as an attempt to answer this thesis research question is described in this section to demonstrate how the previous analysis was considered during the design process, followed by a detailed description of the game. The game is entitled Once Upon a Maths.

3.2.3.1 Theoretical Game Development

Once Upon a Maths is an online adventure videogame with a narrative based on the history of mathematics. It is important to highlight that this game is a free adaptation of the history – real facts described by historians were used to inspire the storyline, that attempts to give a meaningful background to the maths procedures, and concepts learned during the primary school learning. In Once Upon a Maths, the player assumes the role of a time traveller. To achieve that, the players count on the help of characters from Ancient times, who will tell him/her mathematics discoveries from their time and challenge the player to use their knowledge to solve a problem they have. If the player succeeds, the Ancient character gives him/her a passport stamp, allowing the player to follow to the next phase of the game. During the gameplay, the player meets real-life characters, such as Pythagoras and Ada Lovelace.

As demonstrated in section 3.2.1, the curriculum coverage is considered by teachers an essential aspect of game design, and 59% of teachers disagree or totally disagree games

can cover the curricula content. The game tested in the present research is aligned with the official mathematics curriculum for primary school learning in Ireland (Government of Ireland, 1999). The current version of the game was designed to children from first and second classes of the primary school, covering the following curriculum content (Table 9).

| Skill | Description | Minigames |
|------------------------------------|---|------------------|
| Counting and numeration | <ul style="list-style-type: none"> • Count the number of objects in a set • Estimate the number of objects in a set | 3, 5, 6 |
| Extending and using patterns | <ul style="list-style-type: none"> • Recognise pattern, including odd and even numbers | 9 |
| Operations | <ul style="list-style-type: none"> • Develop an understanding of addition and subtraction by combining or partitioning sets • Develop and/or recall mental strategies for addition and subtraction facts • Use mental calculations • Explore repeated addition and group counting | 3, 5, 6 |
| Length | <ul style="list-style-type: none"> • Estimate, compare, measure and record length using non-standard units • Select and use appropriate non-standard measuring units/instrument • Solve and complete practical tasks and problems involving length | 1 |
| Weight | <ul style="list-style-type: none"> • Estimate, compare, measure and record weight using non-standard units • Select and use appropriate non-standard measuring units and instruments | 3 |
| Spatial awareness | <ul style="list-style-type: none"> • Explore, discuss, develop and use the vocabulary of spatial relations • Give and follow simple directions | 2, 7, 8, 9 |
| Representing and interpreting data | <ul style="list-style-type: none"> • Sort and classify objects | 4 |

TABLE 9 ONCE UPON A MATHS CURRICULUM COVERAGE.

The application of the Theoretical Game Development Framework suggests that most of the games adopted by the respondent teachers follow a behaviourist approach. Previous research has demonstrated that this type of game follows traditional methods of teaching and tends to be less engaging than those pedagogically innovative that make the most of the potential of videogames. Once Upon a Maths is an attempt of adopting a different way of playing in the classroom, underpinned by the pedagogy behind the situated learning approach. Situated learning is the part of the humanistic view that envisions learning in real-life occurring frequently. The game narrative is based on the history of mathematics, a science developed by people from ancient times to solve daily-life problems. This context gives the player the possibility of comprehending how the concepts learned in the classroom could be applied in ancient times. All levels of the updated Bloom's taxonomy are covered as part of the learning objectives of the game. The history told by the ancient characters will help the player to memorize concepts, which can later be applied to solve the games. The creation and evaluation features are implemented when the student has the chance of interacting with another student, collaborating and sharing what s/he learned about the game. Moreover, considering the SAMR Model classification, our game would be assigned in the Modification category. A history maths game allows the student to be in a time machine and go back to be part of mathematics history. From the perspective of the game design elements, a collaborative gameplay design was adopted. In research about classroom mathematics games, Plass *et al.* (2013) showed that, when compared to individual and competitive playing, the collaboration resulted in stronger intentions to play the game again and recommend to others. When playing Once Upon a Maths in the classroom, students will have the chance of supporting their friends to get prizes for being a good traveller. One strategy adopted for peer interaction was the use of printed passports. While playing in the classroom,

players receive passports where one get stickers every time s/he finishes one phase of the game (Figure 9).



FIGURE 9 ONCE UPON A MATHS' PASSPORTS.

If a player finishes before his/her colleagues, this student is invited to help a colleague. The passport contains a page called Good Traveller, where the student gets a sticker for every friend s/he helped. At the end of the whole game, the student with more stickers on the Good Traveller page receives a prize. Another aspect considered during the game design is the difference in levels of mathematics anxiety between males and females. The gender differences are already well described (Stoet *et al.*, 2016) and there is evidence that females tend to be more anxious about mathematics than males, even when they have similar levels of performance (Van Mier, Schleepen and Van den Berg, 2019). Once Upon a Maths includes elements that could make the game more attractive and comfortable to be played by female students, like high use of visual learning approach (Pruet, Ang and Farzin, 2016), use of storytelling elements (Giannakos *et al.*, 2012), and reduction of competitiveness elements (Hartmann and Klimmt, 2006).

The game provides visual feedbacks about the player's progress. One example is on the Modern World minigames, where children had to give the instructions to the animal so it could fly. Because there is a list of instructions, the player might make a mistake in only one of them – for instance, step 1 and 2 are correct but step 3 is wrong. The game lets the player know where the mistake was made by turning red the wrong step (Figure 10).



FIGURE 10 VISUAL FEEDBACK IS GIVEN WHEN THE PLAYER MAKES A MISTAKE ON MINIGAME 7.

There was an initial aim of including an assessment monitoring to allow the teacher to check students' progress aligned with curriculum coverage and learning objectives. The time was not enough to develop it, but this is included in the future plans (Chapter 5). The purpose of the game is to be educational, and the chosen genre is an adventure. The choice of the genre is based on the research literature. From the technical point of view, Once Upon a Maths can run in most of the devices with access to a browser. The 2D interface was chosen as it may be easier to run in cheaper low specifications devices, which are common in schools. The game does not include a leaderboard to avoid feelings of anxiety, and children had plenty of time to finish each phase – no chronometer or limit of trials was considered. Players will

get points as they solve the puzzles so that ownership reward will be present. Also, there will be goals to achieve, such as solving the whole puzzles of an island, getting stamps for each conquer, which is expected to provoke an effect of achievement. Feedback was also given to children while they were playing. Every minigame had a message in the screen that, at the beginning of the game, had instructions of how to play. After the first trial, the message changed to let the child know if s/he won or made a mistake. In the latter case, the message always contained an idea of stimulating the player to try again.

Once Upon a Maths was developed with the aim of being an adventure game. Adventure games are known by having educational value, training players to become better problem solvers (Ju and Wagner, 1997) and provide the best foundation for the development of teaching resources (Amory *et al.*, 1999). According to Dickey (2006), adventure games stimulate curiosity as the player always want to know what is going to happen next, besides provoking emotional proximity with the game and its characters. The narrative in adventure games works as a framework for problem-solving. The player thinks through the story and try to integrate the experiences he has in the game into the storyline. For mathematics learning, the player may give meaning to the subject while learning it through a narrative. Even though adventure seems to be a worthy genre for educational games, the results of TCG application have shown that most teachers use puzzle games. This may be related to the fact teachers have restricted time, and puzzle games are shorter and go straight to the point when compared to adventure and role-playing games, which can have a rich (and, sometimes, long) narrative. To keep the advantage of puzzle games without losing the benefits of a rich narrative, Once Upon a Maths will be an adventure game compound of small challenges or

mini games as part of its phases. This way, the player can choose a short game without having to go through a long gameplay and stopping in the middle of it.

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 website¹. The following use-case illustrates the game flow of Once Upon a Maths (Figure 11).

When accessing Once Upon a Maths website, the player finds a landing page where s/he can insert his/her details to log into the system. A new player can access the game after registering, choosing a username and a password, and logging in.

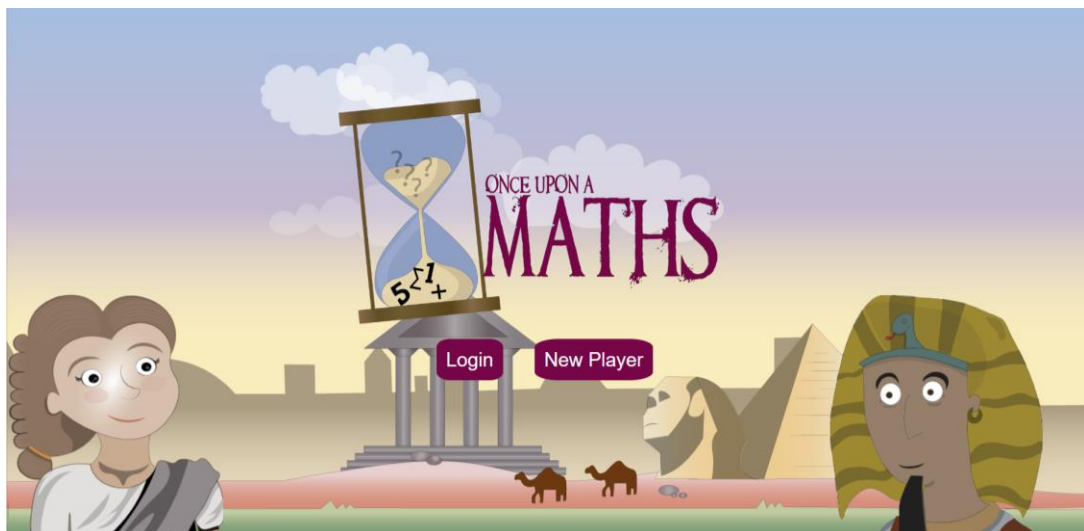


FIGURE 11 LANDING PAGE OF ONCE UPON A MATHS GAME.

After that, the user has access to the page when s/he can find a collection of information. The player can see his/her username and score in the left menu. On the right, the player has access to the videos related to each period that is part of the game narrative.

¹ www.onceuponamaths.epizy.com

The game was structured like this because of planning the software testing phase: the videos would be shown in the projector to the whole classroom before playing each stage. First, the page shows nine islands that represent the different minigames inside Once Upon a Maths (Figure 12). Every three island represents one time period of the history of maths, and these groups of islands are coloured in different ways to highlight their separation. If the player is accessing the game for the first time, all levels will be locked except for the first one.

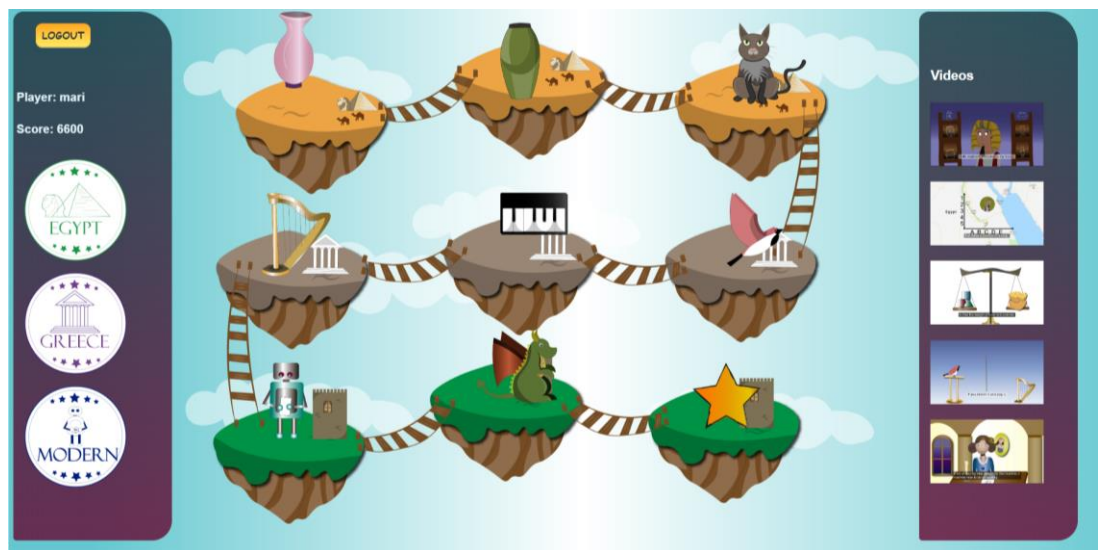


FIGURE 12 LEVELS PAGE

Before playing each phase, the player watches a short animation where a character from that period presents maths concepts and procedures used during those times. The character, who is based on actual historical people, invites the player to use what s/he learned to solve challenges so s/he can progress to the next phase. 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.

In the following sections, Once Upon a Maths is described based on what Schell (2014) presented as a model of the four elements that compose a game, also known as the elemental tetrad. These elements are the story, the mechanism, the aesthetics and the technology behind the game (Figure 13). The story is the sequence of events that unfolds the game, the narrative that guides the gameplay process. The mechanics of the game consists of the rules and procedures executed while playing, and what happens (or what does not happen) when the player tries to do a specific action. The aesthetics are related to the different sensations provoked by the game: how it looks, sounds and feels (Schell, 2014). The different phases of Once Upon a Maths will be presented considering the story and the mechanics of the minigames. In the end, the whole game will be described from the point of view of its aesthetics and technology.

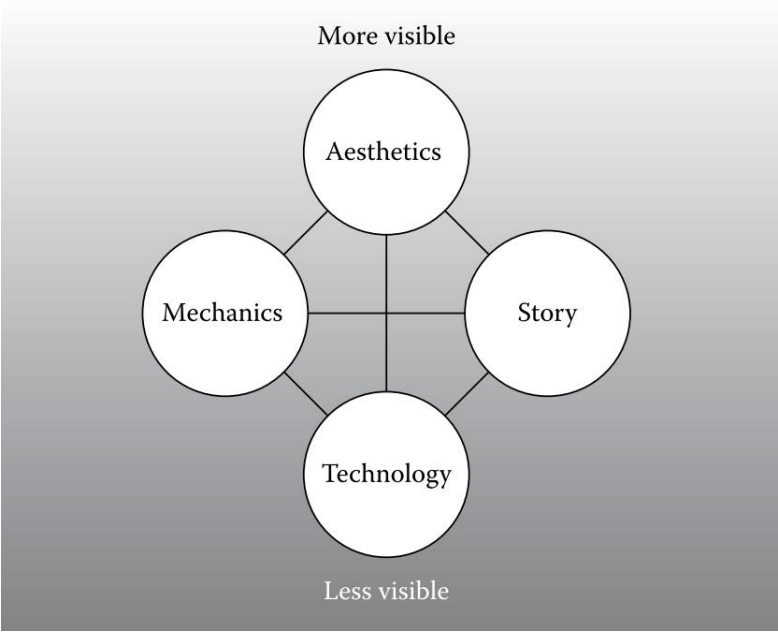


FIGURE 13 THE ELEMENTAL TETRAD BY SCHELL (2014).

Once Upon a Maths is divided into phases. The first phase of the game focus on presenting mathematics from Ancient Egypt (3100 B.C.E – 30 B.C.E). It is presented by Nebamun, a sculptor who invites the player to visit his house and shows the extensive collection of vases designed by himself (Figure 14).



FIGURE 14 NEBAMUN IS THE CHARACTER FROM THE ANCIENT EGYPT PHASE.

This phase contains three minigames, and each minigame is introduced by one animation. During the first animation, to entertain his guest, Nebamun talks about how people from his time used parts of the body to measure things. He describes the concepts of cubit, foot and palm. Nebamun tells the player that a cubit has the same size as the distance from the elbow to the fingertips, while the foot has the size of a foot and a palm has the size of a hand. The animation shows the measurements and compares their sizes to the sizes of different animals (Figure 15). This concept is introduced as the first minigame consists of using parts of the body to measure Nebamun's vases.

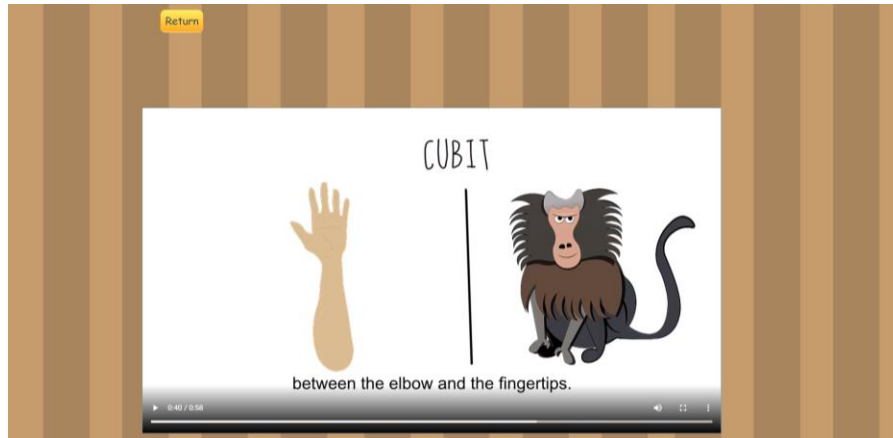


FIGURE 15 THE ANIMATION COMPARES THE PARTS OF THE BODY MEASUREMENTS WITH THE SIZE OF THE ANIMALS

The first minigame is a drag and drop activity where the player must use parts of the body to measure. On the left side of the screen, a platform with a vase is shown, and the player should drag and drop parts of the body s/he thinks would match the size of that vase. The player can drop more than one part of the body – for example, measuring the vase using one foot and two palms – or only one – for example, measuring the vase using one cubit (Figure 16). There is a “clear” button that allows the player to remove the pieces that were dropped and start again. Each part of the body that the player can drag contains a counter with the number of pieces dropped. Every time a piece is dropped, the counter is incremented by one.



FIGURE 16 IN MINIGAME ONE, THE PLAYER USES PARTS OF THE BODY TO MEASURE VASES.

If the player is happy with the pieces dropped, s/he can click on the button “measure”. The system then will check if the answer is correct. In case it is, the platform opens, and the vase goes down so a new vase with different size can appear and the player can keep playing. There are three vases to measure, and they are represented by the start on the left side of the screen. The player gets a new beginning for every right answer. If the player inputs an incorrect answer, the vase breaks and the player has to start again (Figures 17 and 18).



FIGURE 17 IN MINIGAME ONE, IF THE PLAYER WINS, THE VASE GOES DOWN THE PLATFORM.

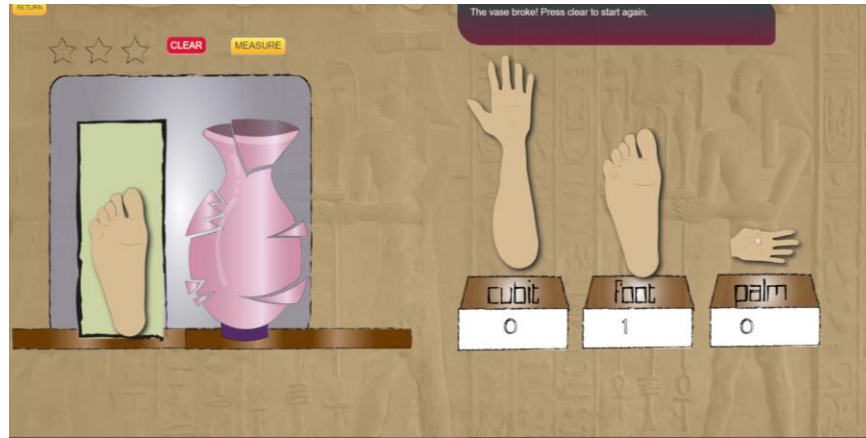


FIGURE 18 IN MINIGAME ONE, IF THE PLAYER LOSES, THE VASE BREAKS.

If the player measures the three vases correctly, s/he gets 100 points and goes back to the level page to go to the next minigame.

In the second animation, Nebamun describes the importance of coordinates to find places on a map. Nebamun explains what coordinates are and how one can use if to find elements on a map or a grid (Figure 19). This animation introduces the second minigame, where the player must organize Nebamun’s vases according to coordinates.



FIGURE 19 THE SECOND ANIMATION INTRODUCES THE CONCEPT OF COORDINATES AND MAPS.

The second minigame is a maze game. The aim is to move the vase through a maze following the coordinates indicated by the character. The screen contains the labyrinth in the left side, and each line is represented by numbers, while the columns are represented by letters (Figure 20). The coordinates are in a sign to the right side, above the arrows that the player can use to move the vase.

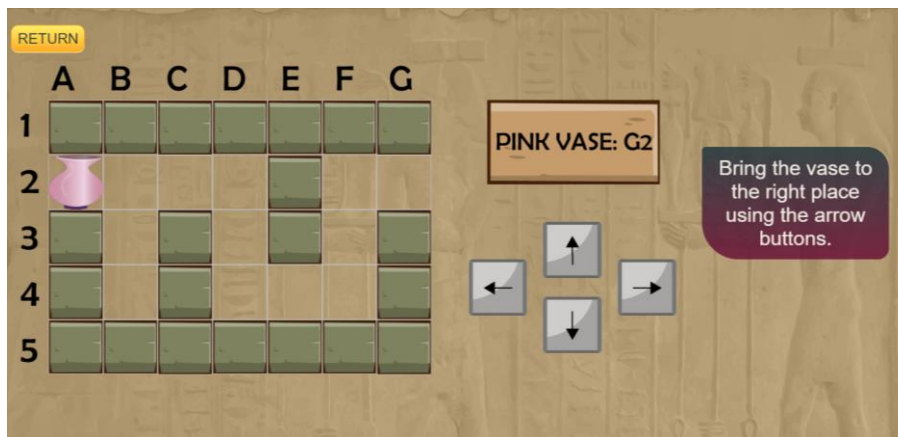


FIGURE 20 IN MINIGAME TWO, THE PLAYER BRINGS THE VASE TO THE RIGHT PLACE BASED ON THE COORDINATES.

If the vase is moved to the right place, indicated by the coordinates, it becomes yellow and the instructions changes, telling the player to press the button “well done” to move to the next challenge (Figure 21). When the player does it, the vase that was moved before disappears and a new vase appears at the beginning of the maze, and the coordinates instructions change.

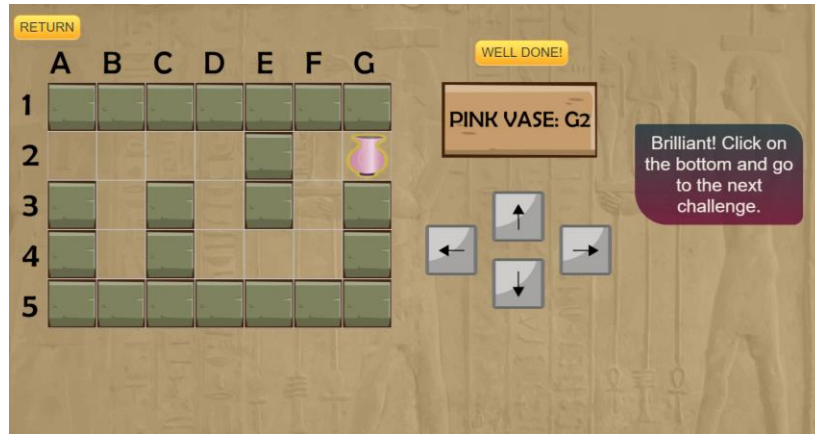


FIGURE 21 SCREENSHOT OF MINIGAME TWO WHEN THE PLAYER SUCCEEDS.

If the player puts the three vases in the right place, s/he gets 100 points and goes back to the level page, where the next minigame is unlocked.

The third animation presents concepts related to the weighing system in Ancient Egypt. Nebamun tells that the weighing system was born with the discovery of metalworking. People from his time used pieces of metal with different weights that were placed in one of the plates of a scale to compare with what was placed in the other plate – for instance, food and animals (Figure 22). This animation introduces the third minigame, where the player will have to use pieces of metal with different values of weight to check how heavy a specific animal is.

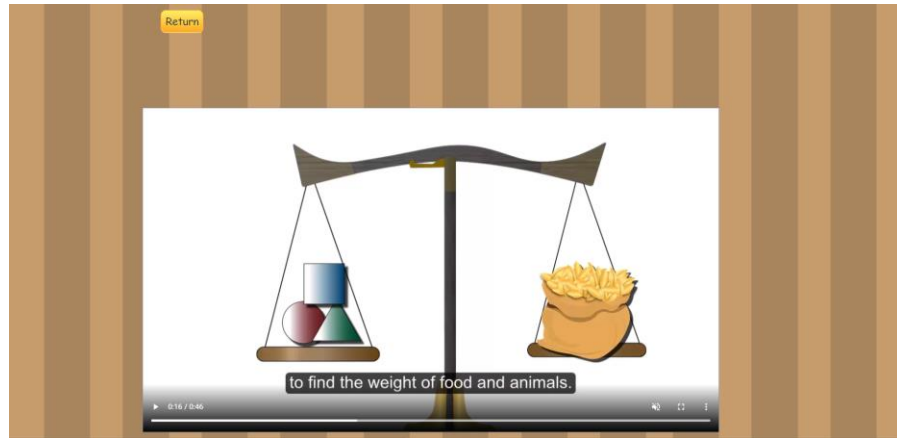


FIGURE 22 THE THIRD ANIMATION INTRODUCES THE WEIGHING SYSTEM ADOPTED DURING ANCIENT EGYPT.

The aim of the minigame 3 is to balance the weight of the bird with the weight of metal pieces. It is a drag-and-drop game, and the left side of the screen shows a piece of furniture with shelves containing pieces of metal. The metals are distributed in a grid where the lines determine the weight of each metal and the columns describe the number of elements contained on that shelf (Figure 23).

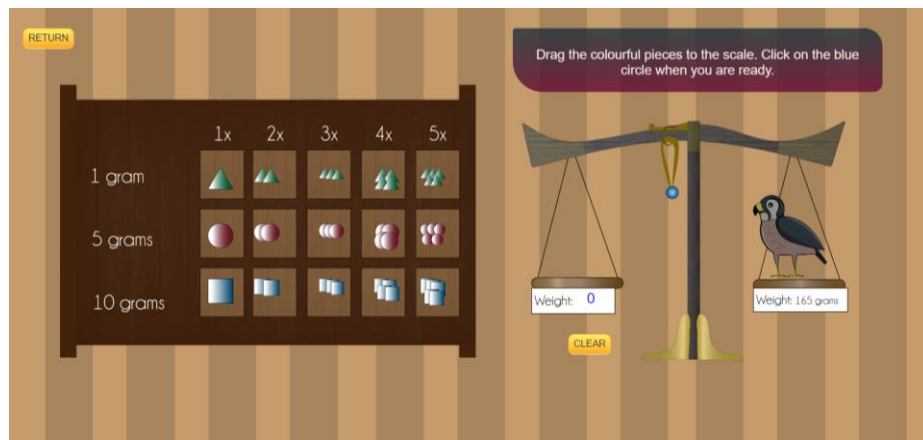


FIGURE 23 IN MINIGAME THREE, THE PLAYER SHOULD FIND THE BALANCE BETWEEN THE PIECES AND THE ANIMAL.

The player should drag and drop the right amount of pieces to the empty plate to find the balance between the metal and the animal weight. Then, pressing the blue circle in the centre of the scale, the system checks if the weights are the same. If the metals are heavier than the animal, the first plate goes down, and the animal spins away (Figure 24). If the opposite happens, the plate with the animal goes down to show it is heavier than the first plate. If both weights are the same, the player moves to the next part and has to weigh another animal. There are three animals to weigh in this phase of the game.



FIGURE 24 IF THE PIECES ARE TOO HEAVY, THE ANIMAL SPINS AWAY

If the player finds the correct weights for all three animals, s/he gets 100 points and goes back to the level page. This level is finished, and the player got a stamp for the Ancient Egypt level, which allows the child to travel to the next phase, now unlocked.

The second phase of the game comprises the maths from the Ancient Greece period (1100 BC – 600 AD). It is presented by the philosopher Pythagoras (Figure 25), in an animation that introduces all three minigames of the Ancient Greece phase. In the video animation, Pythagoras is accompanied by a bird that gets confused when the philosopher

states to be known as the father of mathematics but also the father of music. Pythagoras then explain how maths and music are related, showing that, if one plays a string, then divide in half and play again, then divide it again and play, the sounds will sound all the same but with different pitches. The animation was inspired by the registers that describe a moment where, while Pythagoras heard hammers in a blacksmith's forge and found them to be very pleasant to the ears. He then decided to check the weights of the hammers and discovered that these were related in ratios of whole numbers. Excited about his discovery, Pythagoras invented the monochord and realised there was also a harmonic relationship between the sounds of strings with different lengths (Caleon and Ramanathan, 2008). He came up with the idea that music harmony, or a pleasing combination of sounds, can be achieved when strings length ratios involve the numbers 1, 2, 3 and 4.

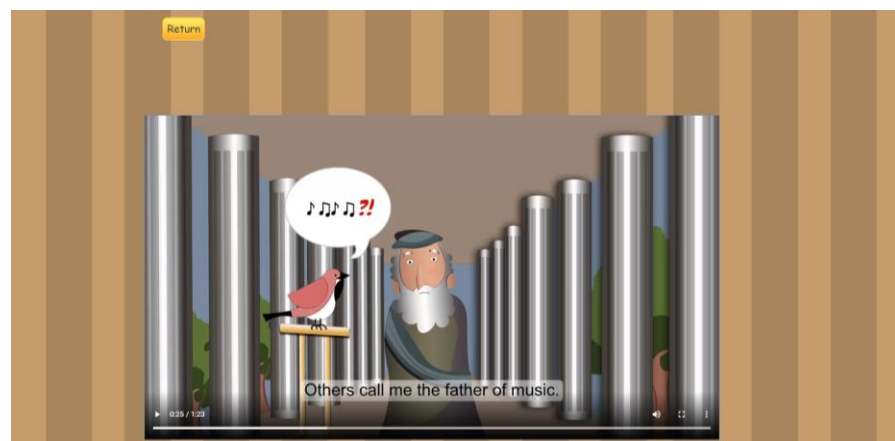


FIGURE 25 THE FOURTH ANIMATION INTRODUCES THE CONNECTION BETWEEN MUSIC AND MATHS.

Minigame 4 is a sorting activity. The screen shows a harp containing pieces with different sizes that represent musical notes. The player should organize those pieces according to their size (Figure 26). After that, the player presses the “play” button and, if the

order is wrong, the instructions on the right side tells him/her to try again. If the order is correct, the player wins 100 points and listens to the sound of the notes. S/he then presses the button “next” allows the player to go back to the level page and go to the next minigame.



FIGURE 26 IN MINIGAME FOUR, THE PLAYER SHOULD ORGANIZE THE NOTES BY SIZE.

The minigame 5 is a drag and drop game. The aim is to match the pieces on the left side with the keys of a piano. Each piece contains circles, and they should match the number above the key. After matching all the pieces, the player presses the button “play”. If the order is incorrect, the instructions let the player know that s/he should try again (Figure 27). If it is correct, the player listens to the piano notes.

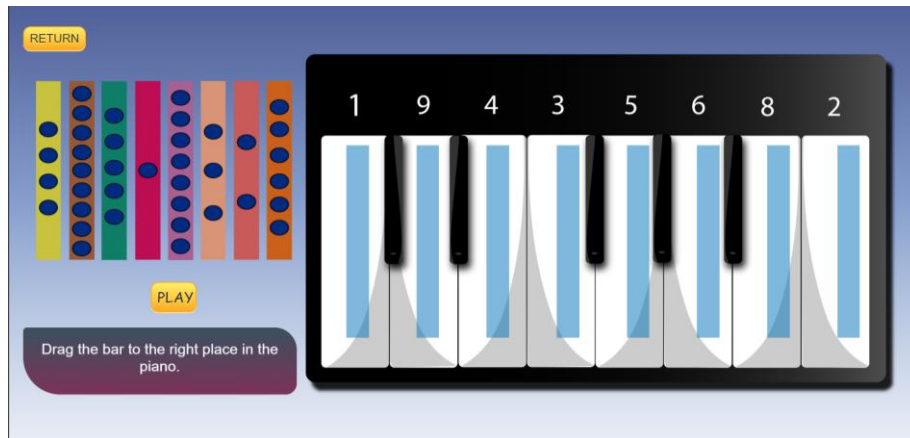


FIGURE 27 IN MINIGAME FIVE, THE PLAYER SHOULD MATCH THE PIECES WITH THE MUSIC SHEET.

In the sixth minigame, the player must follow a piece of sheet music (Figure 28). The piano keys contain the same pieces with circles from the previous minigame. The player should press the keys following the order on the music sheet. Every time a key is pressed, the player can hear the note. After that, s/he should press play. If the order is correct, the music sheet changes and the player plays the second part of the song. The song is “Happy Birthday” to you, and it is divided into three music sheets. After playing the music sheets correctly, the player gets 100 points and a stamp for finishing the challenges of phase 2 of Once Upon a Maths. The player then goes back to the level page to move to the next stage.

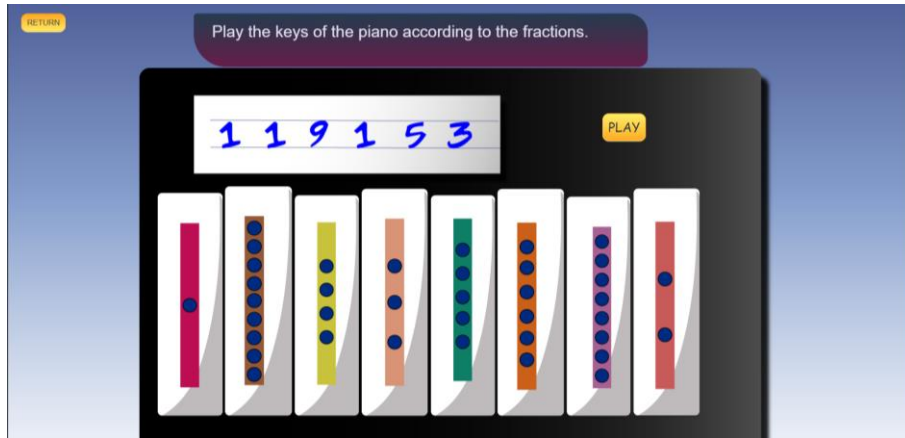


FIGURE 28 IN MINIGAME SIX, THE PLAYER FOLLOWS THE MUSIC SHEET TO PLAY A SONG.

The third phase of the game focuses on the maths 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 (Fuegi and Francis, 2003). She exchanged letters with Charles Babbage, who created the analytical engine, a machine that was able to make calculations (Essinger, 2014). While translating an article about the machine, Ada Lovelace added notes that were three times the length of the article. To the notes, she added an algorithm that could be used by the machine to calculate the sequence of Bernoulli numbers, a sequence of rational numbers which frequently occur in number theory. In the animation, Ada Lovelace tells the player about Babbage's machine and explain what the concept algorithm is and why it is important to write correct instructions so a machine can execute functions in the way it is expected to do (Figure 29).



FIGURE 29 IN THE FIFTH ANIMATION, ADA LOVELACE EXPLAINS HOW ALGORITHMS WORK.

Lovelace also talks about her passion for flying. As a child, Ada was quite interested – almost obsessed – in the possibility of flying. When she was around 12 years old, she studied the patterns of birds’ wings, researched about different materials, like feathers and silk, and worked on sketches of steam-powered flying machines. Those findings are registered in letters Ada sent to her mother (Essinger, 2014). In the animation, Lovelace challenges the player to use algorithms to teach an animal how to fly.

For many years, Lovelace’s achievements were not recognized. Today, to honour women in STEM, the Ada Lovelace Day was created, and it is celebrated every second Tuesday of October. This character is relevant to Once Upon a Maths not only to introduce the player to the concept of algorithms but also because she represents a female mathematician. In comparison to men, women are highly misrepresented by the media in STEM characters (The Lydian Hill Foundation and The Geena Davis Institute on Gender in Media, 2018), and this might result in a lower number of females pursuing careers in STEM

when they grow up. In Ireland, less than 25%, in Science and Technology based careers (Accenture, 2014).

Minigames 7, 8 and 9 are quite similar but with different levels of difficulty. The general aim is to teach an animal how to fly. The player can choose between a unicorn or a dragon and keeps teaching that animal through the three minigames. The screen shows, on the left side, a column with numbers. In the middle, the clouds where the animal should jump into. Each cloud is referent to one of the numbers at the column, and the player should use that to guide the animal, telling it to fly to a cloud referent to a certain number and to which direction the animal should fly to. The instruction is given by dragging and dropping pieces with numbers (referent to the clouds) and arrows (referents to the direction). On the right side of the screen, there are boxes categorized by order of steps, where the player should drop the instructions pieces. If the player makes a mistake, s/he can press the button clear next to the step box (Figure 30).

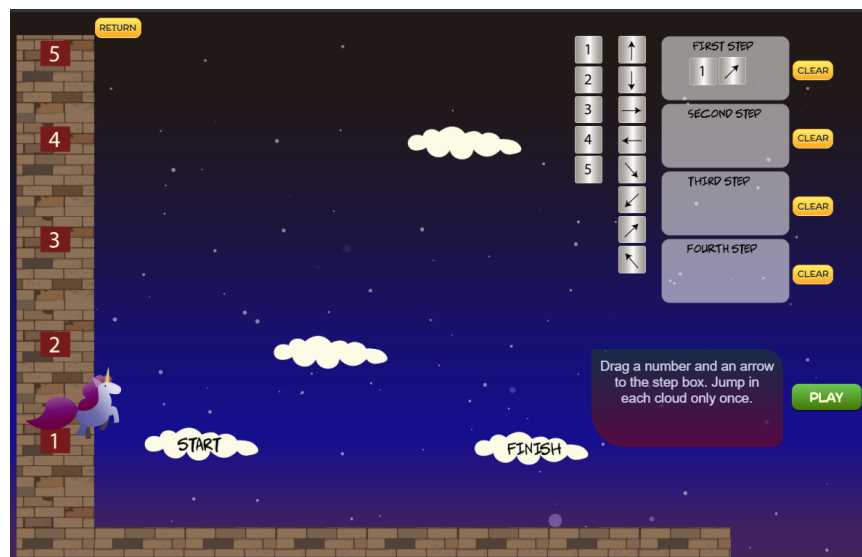


FIGURE 30 IN MINIGAME SEVEN, THE PLAYER DESCRIBES AN ALGORITHM TO TEACH THE ANIMAL HOW TO FLY.

The minigame 8 has the same principles but is a little bit harder. The player has to instruct the animal to jump into all clouds except for the dark one (Figure 31).



FIGURE 31 IN MINIGAME EIGHT, THE PLAYER SHOULD AVOID THE DARK CLOUD.

Minigame 9, again, follow the same mechanisms of 7 and 8. Now, the challenge is to play only into clouds that are related to odd numbers (Figure 32).



FIGURE 32 IN MINIGAME NINE, THE PLAYER SHOULD AVOID EVEN NUMBER CLOUDS.

When one thinks about the game, the idea of a structured playing tool comes to mind. Rules, competition, and scores are elements that can make somebody immersed in the gameplay. However, games today are more than that. They can stand somewhere between the traditional game and an artwork object, as something that stimulates imaginative and cognitive faculties in the subject of aesthetics experience (Kirkpatrick, 2007). The feelings a game provoke are related to this experience and essential to its stubborn success as an element in contemporary culture. This research project is quite multidisciplinary, and the main challenge was to develop a range of skills that goes beyond only designing a game, such as doing graphic design and animating characters. Educational designers tend to focus on scientific knowledge to work on their final products. However, as argued by (Harris and Walling, 2013), the work of the learning designer is composed of both art and science. Visual representations create patterns that help the player to make sense of the game, revealing changes and connections as the game unfolds (Gupta and Kim, 2014). Little is known about how the visual design elements affect children in learning media. In an experiment with 53 students between 9 and 11 years old, (Javora *et al.*, 2019) evaluated the learning outcomes when children were playing one game with two different designs, one considered with high aesthetic value and one with low aesthetic value. The children were divided into two groups, and each one played one version. Then, they had a chance to see the two versions of the game side by side. Although there was no change in their learning results, children preferred the game with high aesthetic value. Therefore, there is a possibility of the visual aspect of the game-enhancing the engagement and retention rate.

The aesthetics of a computer game can include a wide range of aspects, like the story, the mechanics, and the interaction with other players. To describe *Once Upon a Maths*,

I will focus on the visual and audio perceptions. As this is a game based in real stories of the world of maths, I attempted to use real life as a source of inspiration. The scenarios, characters and other elements are all based in images found in History books, paintings, and biographies. The same values to the colour scheme used, to create an identity to each phase of the game the same way people create colour schemes in their imaginations. For instance, if one thinks about Ancient Egypt, the pyramids come to mind together with their sand colour. Ancient Greece brings memories about the marble constructions mostly painted in white and blue. The Modern World makes us think about the metallic shades of a robot. Nevertheless, the graphics of Once Upon a Maths tried to go being bringing the memories children might have constructed from books, movies, and school learning. Graphic elements were also used to give feedback and bring children's focus to some regions of the screen. This overall process of development is described following, highlighting the main aspects of graphic design, organization of elements on the screen, playing guidelines and background sounds.

Once Upon a Maths is a two-dimensional game with a cartoon design style. The game incorporates challenging elements and scenario manipulation, factors that are relevant for problem-solving based games as they allow students to reflect on their manipulations to solve the problem (Hou and Li, 2014). Both scenarios and non-player characters were designed based on real-life elements from human history. The splash page of the game contains a scenario with Nebamun, from Ancient Egypt, and Hypatia, a mathematician from Ancient Greece. In the background, images of the Egyptian pyramids and an ancient Greek construction are illustrated. The page also brings the logo of the game, which contains an hourglass with question marks that are transformed in numbers and maths symbols as the sand falls into the other side (Figure 33).

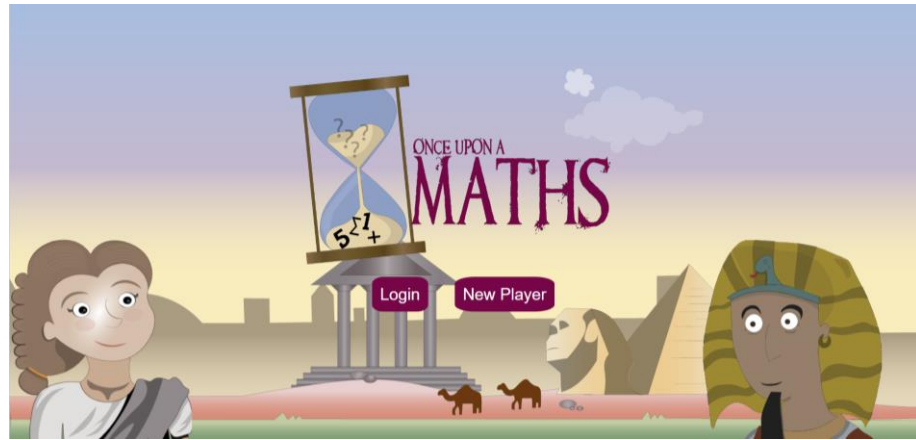


FIGURE 33 SPLASH PAGE OF ONCE UPON A MATHS

The first phase of the game was designed based on the following colour scheme. In Ancient Egypt, yellow was widely used in paintings, although the term used to describe red, so elements like the desert and the gold are perceived as red.



FIGURE 34 COLOUR SCHEME OF ONCE UPON A MATHS PHASE 1.

Yellow was the most prominent colour in the elements of the ancient Egyptian images, like the background of paintings (Nazar, 2017), and this inspired the graphic design of phase 1 (Figure 35). Nebamun, the character that presents stage one of Once Upon a Maths, is identified with elements that remind the ancient Egyptian pharaohs. Although historically, that might not be accurate – after all, Nebamun is a sculptor – this type of characterization allows children to associate the character to the historical period.

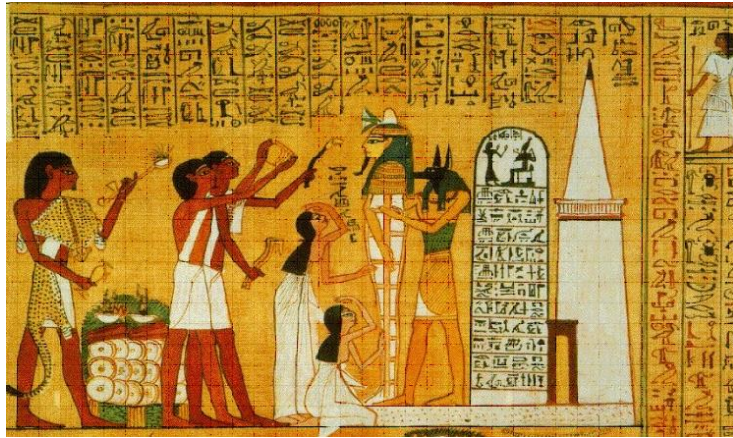


FIGURE 35 PHASE 1 WAS INSPIRED BY REAL-LIFE ANCIENT PAINTINGS (SOURCE: OAKES AND GAHLIN, 2018, P. 419)

Another essential element from this phase is the scale presented in the third minigame, which was based on the image shown in the Papyrus of Hunefer. In this papyrus, the Egyptians describe the weighing of the heart rite, when the heart of the deceased is weighed in the scale against the feather of the goddess Maat (Figure 36), who personifies order and truth (Carelli, 2011). This painting inspires the scale presented in minigame 3.



FIGURE 36 THE SCALE PRESENTED IN MINIGAME THREE WAS INSPIRED BY A REAL ANCIENT PAINTING (SOURCE: THE PAPYRUS OF HUNEFER, 1275 BCE).

For phase two of the game, the following colour scheme was adopted (Figure 37). The white colour was quite popular during Ancient Greece, especially for the use of white marble in the architecture and sculptures. This marble was painted with bright details using colours like red and blue.



FIGURE 37 COLOUR SCHEME OF ONCE UPON A MATHS PHASE 2.

The character from phase 2, Pythagoras, was designed based in the Pythagoras bust, found in the Capitoline Museum, in Rome, Italy (Figure 38).

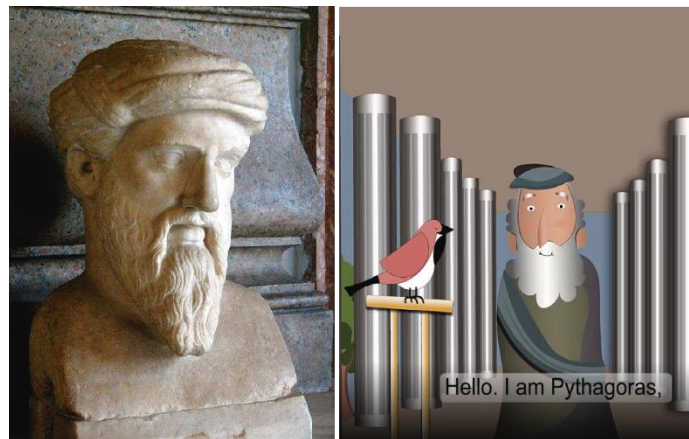


FIGURE 38 THE PHASE 2 CHARACTER REPRESENTS PYTHAGORAS OF SAMOS.

For phase 3 of the game, a mix of classic times with modern figures is applied. Because the game focuses on the development of the first algorithm, a robot is an element that illustrates how mathematics can be used to talk the language of the machines. However,

Ada Lovelace described the first algorithm in the 19th century, so the animation must include elements from her times. Phase 3 was designed based on the following scheme (Figure 39).



FIGURE 39 COLOUR SCHEME OF ONCE UPON A MATHS PHASE 3.

The character, Ada Lovelace, was graphically designed based in paintings made during her times, like the following one (Figure 40).

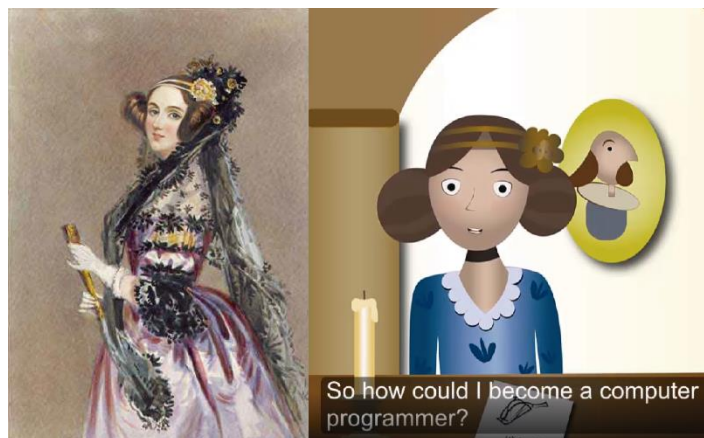


FIGURE 40 ADA LOVELACE CHARACTER WAS DESIGNED BASED ON PAINTINGS FROM HER TIMES, LIKE THIS ONE BY ALFRED EDWARD CHALON (SOURCE: PUBLIC DOMAIN).

Because it is designed to be played in the classroom, Once Upon a Maths is not heavy in sounds. The animations have a music background in low volume to avoid children getting distracted by the song and not focusing on the content and information transmitted by the character. All the songs are composed by Kevin MacLeod, American musician who composed over 2,000 pieces of royalty-free library music and made them available under a

Creative Commons copyright license². Characters voices were provided by the software Animaker Voice³, which allows choosing features such as gender and accent. The voices of the character are not only used during the animation but also to play brief instructions and audio feedback on the minigames.

Once Upon a Maths is available online hosted by Infinity Free⁴, a free website hosting with unlimited disk space and unlimited bandwidth. The front-end was developed using HTML5, CSS and Javascript, together with Bootstrap and jQuery libraries. The backend was developed using PHP and MySQL for the database. The game is responsive for most of the screens and browsers available. However, the interaction and experience are richer when played in larger screens, such as tablets and computers. Players can interact with the game by using the mouse or touching the screen. There is a minimum necessity of typing – the only moment when players have to type is on the registering a new user page and while logging into the game.

The illustrations presented in the game were developed using Adobe Illustrator, a vector graphics editor, and a Wacom creative pen tablet. For the animations, Adobe Character Animator was used. In this software, the user inserts specific layers, such as Right Eyebrow or Smile, and it generates a puppet that can be manipulated by the user, mimicking his/her movements inputted by the camera.

² <https://incompetech.com/>

³ <https://www.animaker.com/voice>

⁴ <https://infinityfree.net/>

3.3 Empirical experiment

The design and development of Once Upon a Maths was a relevant part of this research. However, the attempt of answering the research question is sustained by an empirical experiment to be implemented at Irish primary schools. The main goal of this experiment is to collect data to identify the effects of Once Upon a Maths on mathematics performance and levels of maths anxiety of primary school students. This will be achieved through a pre-test-post-test experiment that will use specific questionnaires to measure mathematics performance and levels of maths anxiety in primary school students before and after playing the game. The basic premise behind this type of experiment design consists in obtaining a pre-test measure of the outcome of interest before administering an intervention, followed by a post-test on the same measurement after the intervention occurs (Frey, 2018). The differences between the pre and post-tests will reveal the effect of Once Upon a Maths on these two metrics. This type of experiment is prevalent in educational research to evaluate the impact of educational interventions on the learning process (Dugard and Todman, 1995). The following diagram describes the main steps of the experiment (Figure 41) and is followed by a detailed description.

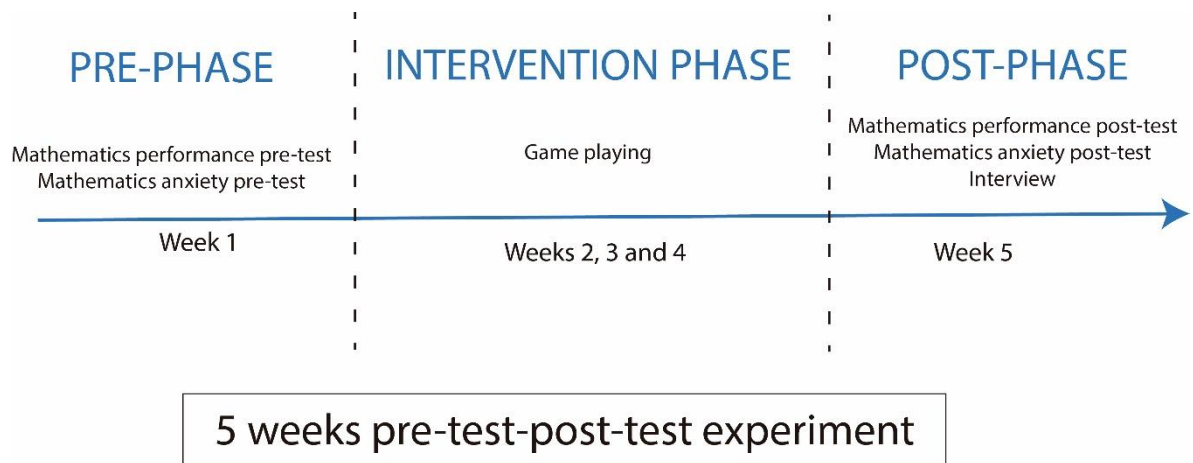


FIGURE 41 STEPS OF THE EMPIRICAL EXPERIMENT.

The experiment will have a duration of 5 weeks, and the aim is to identify how the digital game affects students' mathematics performance and levels of maths anxiety. Each participant class will be visited once per week, and the visit will have a duration between 45 minutes and one hour. From the five weeks', once per week, time frame, the first and last weeks will be dedicated to the implementation of the measurement tools to be adopted as pre and post-tests for mathematics performance assessment and levels of maths anxiety assessment. The final week will also include the implementation of a group interview was implemented to collect students' perceptions of the game. These perceptions add value to future improvements of Once Upon a Maths. The interview will be recorded and transcribed, and the questions can be found in Appendix 2. Other details about the students, like gender and maths grade, will also be collected to be part of the descriptive statistics. The gender information will also be used to evaluate if female students react differently to playing the game when compared to male students.

As identified during the implementation of the Preliminary Multidimensional Self-Reporting Survey, several teachers find difficulty in adopting classroom videogames due to the lack of technology resources. Therefore, 30 tablets will be brought to the classrooms already containing the requirements to access. Once Upon a Maths. In recent years, there was an increase in the popularity of tablet at schools – in the United Kingdom, almost 70% of primary and secondary schools use tablets (Coughlan, 2014). This may be related to the fact that tablets are more affordable than traditional computers, besides having several components and sensors like GPS and cameras, being light-weight and allowing mobile learning (Major, Haßler and Hennessy, 2017). In Ireland, the average class size is around 25 students (Kelleher and Weir, 2016). Therefore, 30 tablets computers should be sufficient. Together with the tablets, students will receive printed passports containing their username and password to access the game. The passport includes three pages for students to get three different stickers as a reward for finishing each phase of the game, besides a page where they can get stickers for each colleague they help. There will also be a collection of pages for students to draw/register their adventure through Once Upon a Maths.

The following sessions describe the tools to be used to collect students' mathematics performance and levels of maths anxiety.

3.3.1 Questionnaires

The mathematics performance and levels of maths anxiety were collected through the implementation of questionnaires. A test was developed based on the content covered by Once Upon a Maths to collect information about students' mathematics performance. The

levels of maths anxiety were measured by a validated self-report questionnaire. Both instruments are described in the following sections.

3.3.1.1 A test for Learning Outcomes on Mathematics for Children (LOMC)

The second questionnaire is the Learning Outcomes on Mathematics for Children, a list of mathematics questions related to the content covered by the game, aiming to measure students' performance on those topics (Appendix 3). The pre and post-tests for LOMC are similar, but questions are disposed in different orders, and some values are different as an attempt to guarantee children do not perform well on the post-test because they recall answers from the pre-test.

3.3.1.2 The unidimensional modified abbreviated math anxiety scale (mAMAS)

The levels of maths anxiety were measured through the Abbreviated Mathematics Anxiety Scale (mAMAS), developed by Carey *et al.* (2017) and that aims to assess maths anxiety in primary school children (Appendix 4). The mAMAS has proven to be reliable and validated (Carey *et al.*, 2017). The mAMAS is based on the Abbreviated Math Anxiety Scale (AMAS) (Hopko *et al.*, 2003), 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 specific situations that involve maths, being 1 equal to low anxiety and 5 equals to high anxiety. The higher is the final, the more anxious the child is. The maximum score is 45, which results from the high level of maths anxiety, and the minimum is 9, resulting in a low level of maths anxiety.

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 was read out

loud and, if students did not understand the item read, the researchers could explain it or reread it. The students answered the questionnaires on paper. Students from the same classroom answered the questionnaire while being together in their classroom. To avoid students to copy the answers from other students, researchers and teachers walked around the room always telling students to be honest and do not copy, trying to make students sure that they were not being tested and there was not right or wrong answer.

3.3.2 Primary schools' selection

Irish schools will be invited to participate in the experiment. The sample of students will be recruited by convenience and schools will be contacted by email and letter (Appendix 5), which will provide details of the experiment what is being tested, what is the game about, and how researchers will interact with the students, the length of the investigation. This experiment is part of a larger project called Happy Maths, which currently includes an agreement with 40 Irish schools.

3.3.3 Participants, procedures, and ethics

All procedures were approved by the Technological University Dublin Ethics Committee (TU Dublin Research Ethics Committee approval number REC-17-29). All participant researchers will apply to be Garda vetted, a procedure of background check completed by the National Vetting Bureau and required for those carrying out relevant work with children or vulnerable persons. Students' parent/guardian will also receive a letter of consent (Appendix 6) stating they allow their children to the participant. The distribution of these letters take place before starting the experiment, so the participants and their parents have time to reflect and agree or disagree to participate.

Students' participation is completely anonymous, and each student will be assigned a username as an ID. This username will be used for students to access the game, sign the pre and post-tests, and have assigned their gender and maths grade. Researchers will not have access to students' names, only their game usernames. Teachers will be responsible for filling a spreadsheet linking students' usernames to their gender and previous maths grade. Students will be classified into two groups: female and male. When considering their maths grades, students will be classified into three groups: low, medium, and high performance.

3.4 Evaluation

The results collected from printed surveys and manually inputted in a digital database. The analysis will be carried out through statistics techniques using the software IBM SPSS Statistics 21. The statistical analysis will consider relevant tests for descriptive statistics, frequencies, and statistical significance to evaluate if Once Upon a Maths had any effect on the maths performance and levels of maths anxiety. The statistical analysis follows a protocol proposed by Henderson (2019), who evaluated the impact of a mindfulness-based intervention before mathematics lessons on levels of maths anxiety in primary school. Although the type of intervention adopted is distinct from the one used in the present research (a digital game), Henderson (2019) also adopted a pre-test-post-test methodology to evaluate the levels of maths anxiety, measured through the mAMAS test.

3.4.1 - Internal reliability of preliminary self-reporting survey via Cronbach

Alpha

Both pre and post-mAMAS tests will have their internal validity tested via Cronbach Alpha measure. Ideally, the Cronbach alpha coefficient should be above 0.7 (DeVellis, 2017).

In 2017, Carey et al. reported that mAMAS had a Cronbach alpha for the whole scale was 0.85, so the reliability is expected to be high.

3.4.2 Overall comparisons

A comparison of pre- and post-results of LOMC and mAMAS will be carried out, considering the whole sample students as a whole and specifically for each participant classroom. Furthermore, specific analysis considering students' gender will also be made.

3.4.3- Assumptions checking of inferential statistics for LOMC and mAMAS

Decisions about the statistical methods to be adopted will be made depending on the data distribution. Both LOMC and mAMAS results will be submitted to the normality test Shapiro-Wilk. Depending on the outcome of this test, the statistical method that will compare pre and post-tests will be chosen. If the data is normal, and a parametric test is used, equality of variance will also be tested through Levene's test.

3.4.4 - Hypothesis testing

As an attempt to accept or reject the hypothesis described in section 3.1, page 56, a set of comparisons will be performed. Empirical experiments will be conducted and measurements of the LOMC and the mAMAS will be collected before and after playing the game. If the data is normally distributed, a paired sample t-tests will be used to evaluate the differences in LOMC and mAMAS scores before and after playing the game. This test is a parametric hypothesis test. If the data distribution is not normal, the Wilcoxon signed-rank test will be applied. This test is a non-parametric hypothesis test that compares repeated measurements on a single sample to assess whether their population mean ranks differ. Considering that previous research demonstrated female students have higher levels of maths

anxiety than male students, an analysis between the two groups of female and male students considering the levels of maths anxiety will be carried out. If the distribution of the data is normal, the test to compare the levels of maths anxiety in both pre and post-mAMAS tests between female and male students will be carried out through Independent-samples t-test. If the distribution is non-normal, Mann-Whitney U test will be used. In case the difference between the two groups is significant, an analysis to check if the differences between pre and post-test for every participant considering his/her gender will be carried out. This will be done by evaluating through an Analysis of covariance (ANCOVA). According to Henderson (2019), when these two groups of students have significantly different levels of maths anxiety before the intervention (playing Once Upon a Maths), this has to be considered before comparing the pre and post-tests. Therefore, the pre levels of maths anxiety have to be adopted as a covariant.

Due to the complexity of this experiment and the relevance of the social environment aspects when situated learning approach is adopted, all the analysis previously described will be carried out considering specific scenarios. First, the whole group of participants will be evaluated as one sample. Then, a class-specific comparison will be performed, and each classroom will be evaluated separately.

3.4.5 - Qualitative evaluation with group interviews

As already described at section 3.3, a group interview will be carried out in the final week of the experiment. Students will be asked questions about the game, and every participant will have a chance to answer every question. The interview will be guided by the following questions:

- Tell me what you like the most on the game.
- Tell me something you didn't like in the game.
- Who was your favourite character?
- Which game was the hardest one? Why?
- How did you feel when you were playing?
- Did you like to help other players? Why?
- How did you feel when you couldn't solve a challenge in the game?
- What would you change in the game?
- Is this a game that you would play only in school, or would you play it in your own free time?
- Do you have any comments about the game?

From the beginning of the session, the researchers will make sure students can feel free to express their opinions, even if their perceptions about the game are negative. They will be stimulated to describe what type of emotions they felt while playing, what they think about the characters of the game, and what were their favourite or least favourite phases of the game. The group interviews will be recorded and transcribed by the researchers. The results will be discussed through a reflection about students' perceptions of Once Upon a Maths.

3.5 Strengths and limitations

The main novelty of the present work consists of evaluating the effects of a situated learning game on the mathematics performance and maths anxiety of primary school children. The game to be tested was designed and developed based on 3 years of research,

including the collection and deployment of information provided by teachers. By the time this thesis was written, no similar digital game was identified, especially considering the unique approach of using the history of mathematics as a game narrative. The hypothesis is tested based on a structured empirical experiment, including tools that were validated by previous researchers. The analysis is made by different angles, using quantitative and qualitative measurements. The students will play the game inside the classrooms, so the subjects will be in an environment that is part of their routine.

The work has, however, limitations. First, the game was tested considering a specific scenario: primary school classrooms in Ireland. Therefore, results might not reflect a general reflection about using situated learning digital games in classrooms from other countries. There is also a difficulty in measuring the efficacy and legitimacy of educational practices as several variables must be considered and can influence the experiment results. This work is a combination of different areas of research: design and development of DGBL, educational research and psychological research. These areas have distinct methodologies and, due to time constraint, not all of them could be included. However, there is an attempt to cover the collection of the data necessary to understand if the game has any effect on the mathematics performance and levels of maths anxiety.

4 Results

This chapter describes the results of Once Upon a Maths evaluation in Irish primary schools classrooms. The chapter brings an overview of the context where the experiment was carried out and the results of the statistical analysis that evaluated possible differences between pre and post-tests to measure maths performance and levels of maths anxiety.

4.1 Descriptive statistics and demographics

Once Upon a Maths was tested by users from three different classrooms (two first classes and one second class) from two schools (Figure 42).



FIGURE 42 STUDENTS ARE TESTING ONCE UPON A MATHS.

One is a catholic co-educational (mixed-gender) school located in Dublin. This school covers the primary level of education and has almost a thousand students enrolled currently. Two classrooms from this school participated in the present experiment and will be referred to as Classroom 1 (1st class) and Classroom 2 (1st class). The other school is a

catholic rural co-educational school located in county Kildare. It is a primary level school and has around 200 students registered currently. One classroom from this school participated in the present experiment and will be referred to as Classroom 3 (2nd class). In total, the game was played by 88 children, but part of the data was incomplete because not every student attended school in every gameplay session. After cleaning the missing data, the experiment resulted in the analysis of information coming from 73 students who attended the whole 5 weeks of the experiment. The following table presents the frequency of students per school and in total, also describing the number and percentage of students per gender (Table 10).

| School | N | Percentage per total | Female | Percentage per total | Male | Percentage per total |
|-------------------------------------|----|----------------------|--------|----------------------|------|----------------------|
| Classroom 1 (1 st class) | 26 | 36% | 14 | 19% | 12 | 16% |
| Classroom 2 (1 st class) | 23 | 32% | 12 | 16% | 11 | 15% |
| Classroom 3 (2 nd class) | 24 | 33% | 9 | 12% | 15 | 21% |
| Total | 73 | 100% | 35 | 48% | 38 | 52% |

TABLE 10 NUMBER OF STUDENTS PER SCHOOL CONSIDERING GENDER.

The participants were classified by their teachers according to their previous maths grades. The following table described this classification, which divided the class in low, medium, or high maths performance (Table 11).

| Groups | Grade |
|--------|------------------------------------|
| Low | students with a grade from 1 to 3 |
| Medium | students with a grade from 4 to 6 |
| High | students with a grade from 7 to 10 |

TABLE 11 CLASSIFICATION ACCORDING TO MATHEMATICS GRADE.

Most of the students were classified as having medium (48%) or high (36%) performance. The following table shows the distribution of students with low, medium and high performance according to each class.

| School | Low | Percentage | Medium | Percentage | High | Percentage |
|-------------------------------------|------------|-------------------|---------------|-------------------|-------------|-------------------|
| Classroom 1 (1 st class) | 6 | 8% | 13 | 18% | 7 | 10% |
| Classroom 2 (1 st class) | 6 | 8% | 10 | 14% | 7 | 10% |
| Classroom 3 (2 nd class) | 0 | 0% | 12 | 16% | 12 | 16% |
| Total | 12 | 16% | 35 | 48% | 26 | 36% |

TABLE 12 DISTRIBUTION OF STUDENTS ACCORDING TO PERFORMANCE CLASSIFICATION.

When considering gender, the majority of female was classified as having medium performance, while most male students as having high performance (Table 13).

| Maths performance | Female | Percentage | Male | Percentage |
|--------------------------|---------------|-------------------|-------------|-------------------|
| Low | 6 | 50% | 6 | 50% |
| Medium | 20 | 57% | 15 | 43% |
| High | 9 | 36% | 16 | 64% |

TABLE 13 DISTRIBUTION OF STUDENTS ACCORDING TO THE PERFORMANCE CONSIDERING THE GENDER.

As described in Chapter 3, the levels of maths anxiety is evaluated before and after students play Once Upon a Maths by the mAMAS test. The pre-mAMAS had a Cronbach alpha of 0,754 while the post-test had a Cronbach alpha of 0,858, suggesting mAMAS is reliable to be used to measure maths anxiety both before and after playing the game.

The mean score for the pre-mAMAS was 19.67, while the post-mAMAS was 20.53, showing a slight increase in the levels of maths anxiety after playing Once Upon a Maths. For the mathematics performance, an increase from 7.05 to 8.3 was identified when comparing the means for the pre and post-LOMC (Table 14).

| | | Pre-mAMAS | Post-mAMAS | Pre-LOMC | Post-LOMC |
|-----------------------|-----------|------------------|-------------------|-----------------|------------------|
| Mean | | 19.67 | 20.53 | 7.0504 | 8.32 |
| Std. Deviation | | 6.76 | 8.59 | 2.03 | 1.82 |
| Percentiles | 25 | 14.50 | 14.00 | 5.50 | 7.50 |
| | 50 | 21.00 | 19.00 | 7.50 | 8.33 |
| | 75 | 24.00 | 27.50 | 8.30 | 10.00 |
| | 90 | 30.00 | 32.60 | 10.00 | 10.00 |

TABLE 14 DISTRIBUTION ACCORDING TO THE MEAN, STANDARD DEVIATION, AND PERCENTILES OF THE PRE- AND POST-MAMAS AND PRE-AND-POST-LOMC.

Based on Devine (2017), high levels of maths anxiety were defined based on the scores at or above the 90th percentile, which corresponded to raw scores of 30 and above. In the present research, around 11% of the students that participated in the study had a score equal or above 30 points in the pre-mAMAS and 17% in the post-mAMAS. Table 15 described the distribution of students according to the results of pre and post-mAMAS and pre- and post-LOMC.

| | | Pre-LOMC | Post-LOMC | Pre-mAMAS | Post-mAMAS |
|---------------|-----------------------|-----------------|------------------|------------------|-------------------|
| Male | N | 38 | 38 | 38 | 38 |
| | Std. Deviation | 2.02142 | 1.85415 | 5.499 | 6.909 |
| | Median | 7.2500 | 8.0000 | 17.00 | 16.00 |
| | Mean | 7.0311 | 8.0568 | 17.24 | 16.79 |
| Female | N | 35 | 35 | 35 | 35 |
| | Std. Deviation | 2.08190 | 1.77918 | 7.083 | 8.483 |
| | Median | 7.5000 | 9.0000 | 23.00 | 26.00 |
| | Mean | 7.0714 | 8.6234 | 22.31 | 24.60 |
| Total | N | 73 | 73 | 73 | 73 |
| | Std. Deviation | 2.03642 | 1.82831 | 6.764 | 8.599 |
| | Median | 7.5000 | 8.3300 | 21.00 | 19.00 |
| | Mean | 7.0504 | 8.3285 | 19.67 | 20.53 |

TABLE 15 DISTRIBUTION OF PRE- AND POST-MAMAS AND PRE- AND POST-LOMC RESULTS ACCORDING TO STUDENTS' GENDER.

4.2 Inferential statistics on overall comparisons

To better understand the data and submit it to the right statistical method of evaluation, the normality of the data was assessed. The normality distribution of the mAMAS results was tested using the Shapiro-Wilk test. The pre mAMAS test is significantly different from normal (N=73, p=0.049, Skewness =0.180; Kurtosis = -0.855). The post-mAMAS test was also non-normally distributed (N=73, p=0.004, Skewness =0.607; Kurtosis = -0.350). When the values of LOMC were submitted to normality test, it was identified that both pre LOMC test (N=73, p=0.004, Skewness =-0.255; Kurtosis = -0.622) and post LOMC test (N=73, p=0.00000006, Skewness =-1.373; Kurtosis = 2.363) were not normally distributed. Based on these results, a non-parametric statistics test should be used to evaluate if playing Once Upon a Maths had any effect on the mathematics performance and levels of maths anxiety.

4.2.1 Effects on the levels of maths anxiety

As previous literature demonstrates a difference between male and female students when considering the levels of maths anxiety, Mann-Whitney U Test was used to evaluate if students' gender had an impact on the mAMAS results. The analysis of the pre-mAMAS suggests female students (Md=23, n=35) had a significant higher level of maths anxiety than male students, (Md=17, n=38) ($U=384$, $z=-3.111$, $p=0.02$, $r=0.36$). A similar result is found when evaluating the levels of maths anxiety after playing Once Upon a Maths, with female students (Md=26, n=35) being significantly more anxious than male students (Md=16, n=38) ($U=308$, $z=-3.948$, $p=0.000079$, $r=0.46$).

Statistical analysis was conducted to compare the pre and post-mAMAS test answered by the students to identify if Once Upon a Maths has any effect on the levels of maths anxiety. As the samples are not normally distributed, the Wilcoxon signed-rank test, a non-parametric statistical hypothesis test, used to compare the two related samples. The analysis revealed no reduction in Maths anxiety after playing Once Upon a Maths ($z = -0.929$, $p = 0.353$). Although no differences were found between the pre and post-mAMAS test when evaluating the whole group, a more specific analysis considering the gender is necessary as there was an increase of the maths anxiety score for female students after playing the game. Following the protocol used by Henderson (2019), an Analysis of Covariance (ANCOVA) was performed considering the pre-mAMAS results as a covariate to compare if the score differences between pre and post-mAMAS had any difference when considering the student gender. The pre-AMAS is considered as the differences between female and male students for this score were significant, and that might influence the comparison with the post-game play score. Preliminary checks were conducted to ensure that there was no

violation of the assumptions of normality, linearity, homogeneity of variances, homogeneity of regression slopes, and reliable measurement of the covariate. The results suggest that playing Once Upon a Maths might have increased the levels of maths anxiety in female students. When comparing the score difference between the pre and post-mAMAS, adjusting it for pre-intervention scores, there is a significant difference between female and male students, with a $p=0.017$ and a partial eta squared = 0.079. This partial eta square reveals that 7.9% of the changes on the levels of mAMAS after playing the game can be related to the gender, which is small effect size.

4.2.2 Effects on mathematics performance

Statistical analysis was conducted to compare the pre and post-LOMC tests answered by the students to identify if Once Upon a Maths has any effect on the mathematics performance. As the samples are not normally distributed, the Wilcoxon signed-rank test, a non-parametric statistical hypothesis test, used to compare the two related samples. The test revealed students had a higher mathematics performance in the maths test after playing Once Upon a Maths, with a large effect size according to Cohen (1988) ($z = -4.407$, $p = 0.000011$, $r=0.51$).

To comprehend if there was any difference between female and male students when considering their results on the maths performance test, Mann-Whitney U Test was carried out considering each group. The analysis of the pre-LOMC suggests no difference between female students (Md=7.5, n=35) and male students, (Md=7.25, n=38) ($U=651$, $z=-0.150$, $p=0.881$, $r=0.017$). Similar result is found when evaluating the LOMC results after playing Once Upon a Maths, with female students (Md=9, n=35) having similar performance as male students (Md=8, n=38) ($U=524$, $z=-1.608$, $p=0.108$, $r=0.18$).

4.3 Inferential statistics on class-specific comparisons

The same analysis previously described for the whole group of students was carried out, considering each classroom separately.

4.3.1 Classroom 1 (1st class)

Classroom 1 is part of a school located in a suburb of Dublin. Students are at the 1st class level of primary school education.

4.3.1.1 Effects on the levels of maths anxiety

When evaluating this classroom, Mann-Whitney U Test suggests female students (Md=20.5, n=14) had a significantly higher level of maths anxiety than male students, (Md=15.5, n=12) when considering the results obtained from the pre-mAMAS (U=43, z=-2.091, p=0.036, r=0.24). However, when looking at the levels of maths anxiety after playing Once Upon a Maths, the difference between female (Md=21.5, n=14) and male (Md=15.5, n=12) students considering their post-mAMAS scores is not significant (U=48, z=-1.806, p=0.063, r=0.21).

Wilcoxon signed-rank test was performed to evaluate if Once Upon a Maths had any effect on the levels of maths anxiety for this classroom after playing the game. The test revealed no change in maths anxiety after playing Once Upon a Maths (z = -1.187, p =0.235). Once again, based on the protocol proposed by Henderson (2019), an Analysis of Covariance (ANCOVA) was performed considering the pre-mAMAS results as a covariate to compare if the score differences between pre and post-mAMAS had any difference when considering the student' gender. The results suggest that for this classroom playing Once Upon a Maths

had no effects on the levels of maths anxiety when adjusting it for the pre-intervention and considering student's gender ($p=0.550$, partial eta squared = 0.016).

4.3.1.2 Effects on mathematics performance

A comparison of the pre and post-LOMC tests students in this classroom had a higher mathematics performance in the maths test after playing Once Upon a Maths, with a medium effect size ($z = -3.730$, $p = 0.000191$, $r=0.43$). The Mann-Whitney U test was carried out considering each gender group for this classroom to comprehend if there was any difference between female and male students when considering their results on the maths performance test. The analysis of the pre-LOMC suggests no difference between female students ($Md=7.5$, $n=14$) and male students, ($Md=6.15$, $n=12$) ($U=61$, $z=-1.201$, $p=0.14$, $r=0.017$). Similar result is found when evaluating the LOMC results after playing Once Upon a Maths, with female students ($Md=9.75$, $n=14$) having similar performance as male students ($Md=9.16$, $n=12$) ($U=83$, $z=-0.055$, $p=0.956$, $r=0.006$).

4.3.2 Classroom 2 (1st class)

Classroom 2 is part of a school located in a suburb of Dublin. Students are at the 1st class level of primary school education.

4.3.2.1 Effects on the levels of maths anxiety

The comparison between female ($Md=24.5$, $n=12$) and male ($Md=21$, $n=11$) students' levels of maths anxiety before playing the game reveals both have the same level of maths anxiety. There was no significant difference between females' and males' degrees of maths anxiety for this class ($U=52$, $z=-0.867$, $p=0.386$, $r=0.10$). Similar results can be found when looking at the levels of maths anxiety after playing Once Upon a Maths, as

female (Md=27, n=12) and male (Md=20, n=11) students had no significant difference between their levels of maths anxiety in the post-test ($U=40.5$, $z=-1.572$, $p=0.116$, $r=0.18$).

Wilcoxon signed-rank test was performed to evaluate if Once Upon a Maths had any effect on the levels of maths anxiety for this classroom after playing the game. For this class, the analysis revealed no reduction in Maths anxiety after playing Once Upon a Maths ($z = -0.122$, $p = 0.903$). Analysis of Covariance (ANCOVA) was performed considering the pre-mAMAS results as a covariate to compare if the score differences between pre and post-mAMAS had any difference when considering the student's gender. Playing Once Upon a Maths had no effects on the levels of maths anxiety when adjusting it for the pre-intervention and considering student's gender ($p=0.141$, partial eta squared = 0.105).

4.3.2.2 Effects on mathematics performance

Differently from the previous classroom, this group did not show a significant difference between the mathematics performance test done before and after playing Once Upon a Maths ($z = -1.450$, $p = 0.147$, $r=0.17$). The Mann-Whitney U test was carried out considering each gender group for this classroom to comprehend if there was any difference between female and male students when considering their results on the maths performance test. The analysis of the pre-LOMC suggests no difference between female students (Md=8.3, n=11) and male students, (Md=8.3, n=11) ($U=63$, $z=-0.190$, $p=0.849$, $r=0.022$). Similar result is found when evaluating the LOMC results after playing Once Upon a Maths, with female students (Md=10, n=11) having similar performance as male students (Md=7.5, n=11) ($U=39$, $z=-1.720$, $p=0.085$, $r=0.20$).

4.3.3 Classroom 3 (2nd class)

Classroom 2 is part of a school located in the rural area of Kildare. Students are at the 2nd class level of primary school education.

4.3.3.1 Effects on the levels of maths anxiety

For classroom 3, the comparison between female (Md=24, n=9) and male (Md=13, n=15) students' levels of maths anxiety before playing the game reveals significant differences ($U=22$, $z=-2.726$, $p=0.006$, $r=0.32$). Similar results can be found when looking at the levels of maths anxiety after playing Once Upon a Maths, as female (Md=29, n=9) and male (Md=12, n=15) students had significant difference between their levels of maths anxiety in the post-test ($U=13$, $z=-3.261$, $p=0.001$, $r=0.38$).

Wilcoxon signed-rank test was performed to evaluate if Once Upon a Maths had any effect on the levels of maths anxiety for this classroom after playing the game. There was no change in the levels of maths anxiety after playing Once Upon a Maths ($z = -0.517$, $p = 0.605$). Analysis of Covariance (ANCOVA) was performed considering the pre-mAMAS results as a covariate to compare if the score differences between pre and post-mAMAS had any difference when considering the student's gender. Playing Once Upon a Maths had an impact on the levels of maths anxiety when adjusting it for the pre-intervention and considering student's gender ($p=0.028$, partial eta squared = 0.209) for this classroom. This partial eta square reveals that 20.9% of the changes on the levels of mAMAS after playing the game can be related to gender, which is large effect size. Therefore, for this classroom, females tend to get more anxious after playing Once Upon a Maths than males.

4.3.2.2 Effects on mathematics performance

Playing Once Upon a Maths resulted in a significant difference in the mathematics performance for this group ($z = -2.337$, $p = 0.19$, $r=0.27$). The Mann-Whitney U test was carried out considering each gender group for this classroom to comprehend if there was any difference between female and male students when considering their results on the maths performance test. The analysis of the pre-LOMC suggests no difference between female students ($Md=6.3$, $n=9$) and male students, ($Md=6.67$, $n=15$) ($U=46.5$, $z=-1.273$, $p=0.203$, $r=0.14$). A similar result is found when evaluating the LOMC results after playing Once Upon a Maths, with female students ($Md=8$, $n=9$) having similar performance as male students ($Md=8.67$, $n=15$) ($U=57$, $z=-0.641$, $p=0.522$, $r=0.075$).

The following table summarizes the results of the classroom specific analysis (Table 16):

| Classroom | Levels of maths anxiety | | | | Maths performance | | |
|-----------|----------------------------------|-----------------------------------|-------------------------------|--|-------------------------------------|------------------------------------|-------------------------------|
| | Pre intervention (male x female) | Post intervention (male x female) | Intervention effect (general) | Intervention effect (considering gender) | Before intervention (male x female) | After intervention (male x female) | Intervention effect (general) |
| 1 | higher in female | not significant | not significant | not significant | not significant | not significant | increase |
| 2 | not significant | not significant | not significant | not significant | not significant | not significant | not significant |
| 3 | higher in female | higher in female | not significant | higher in female | not significant | not significant | increase |

TABLE 16 SUMMARY OF THE RESULTS OF THE EMPIRICAL EXPERIMENT.

4.4 Group interviews

In the final week of the experiment, students also took part in a group interview. The full transcription of the group interviews can be found in Appendix 7. The discussion was guided by open questions that were read out loud to the students, and each of them had a

chance to answer each question. The interviews were recorded and transcribed after the experiment. The first question of the interview was “Which game you liked the most: Ancient Egypt, Ancient Greece, or Modern World?”. The aim was to stimulate children to talk about the games and highlight the game elements they appreciate. Most students in the second class said they preferred Modern world minigames. When asked why students said they like it because it was more challenging than the others. In the group of students in the first class, most children preferred Ancient Egypt and Ancient Greece phases, as they could “play music” and “measure stuff”. Many of those said they did not like Modern World because “it was too hard”. It was quite clear that different children have different levels of difficulty and, although some find the challenging stimulating, others felt it was disengaging. One child from second class had an interesting perspective about the Modern World game. In her/his opinion, this was the best part of the game “because it was very different from the other ones and there wasn’t a lot of maths on it”. Another student from first-class said, before I made any question, “I love the game”, and I asked if s/he liked maths, to what s/he answered, “no, I hate maths”. One of his/her friends said “but the game is about Maths”, to what the first student answered with a confused face. They both laughed and changed the subject.

An interesting episode happened in the second class group. I asked one of the students what s/he would change in the game, and the child said: “I would make it easier”. I made the same question to another student, who answered: “I would make it harder”. Then, a third child interfered and said: “You could set up a difficulty setting on it so people could pick how hard the game would be”.

When asked what game was the hardest one and what was the easiest one, most children from the first and second classes said Modern World and Ancient Egypt. In fact, the

idea was, although only three phases area available, to show how the history allowed Maths to become more and more sophisticated, as new concepts were built based and inspired by previous discoveries.

When asked about their favourite character in the game was, most of the children in the first and second classes answered “Ada Lovelace”. I took the opportunity to explain that she existed in real life and was a very famous mathematician. In one of the first class groups, one child said the unicorn, from the Modern World phase, was her/his favourite character, then asked if the unicorn was real as well. All children got excited with the idea and started to wonder if the dragon was also real – after all if Ada Lovelace and Pythagoras was real, why not the unicorn and the dragons? In fact, many children created a connection with the animals they chose while playing Modern World. When asked to describe in one word how they felt when they could not solve one of the puzzles, a child said: “I was horrified, because I thought my dragon would die and I would have to arrange a funeral, and that would cost a lot of money”. Another student was very concerned that her unicorn felt many times and suggested to “have a person bringing the unicorn back to the place, so we don’t think he died”. The story behind the game allowed them to connect with the characters and gave scope to their imagination. Students’ reproduced their connection with the characters while drawing them in the passports (Figure 43).



FIGURE 43 STUDENTS DREW THEIR MEMORIES ON THE PASSPORTS.

They were also asked to describe in one word how they felt while playing, and most of the answers were positive. Words like “happy”, “good”, and “clever” appeared many times. Less frequently, some children said they felt “confused”, “worried”, and “bored”. The students were also asked if they enjoyed working in a group for some of the challenges. All of them answered “yes” and, when asked why, some gave answers related to the good feeling of being helpful (e.g., “because I like being nice”); the spread of collaboration (e.g., “because when you help someone, he helps more people”), or the fact they learned more about the game when explaining it to another child (e.g., “because I got to figure out... If I didn’t get something before I got it when I could do it again”). One of the students answered, honestly, “I like to help because I get more stickers”. An interesting dialogue related to the collaboration happened when one of the students said s/he didn’t like the Modern World game:

Student 1: I didn’t like the last one. It was really hard, and I couldn’t do it!

Student 2: But we worked together on that one, and you did it!

Student 1: Yes, that’s true.

When asked about what they would change in the game, many students said they would like to have more levels. One of the limitations of Once Upon a Maths is the necessity of designing and developing new scenarios and mechanics for every minigame, which demands time and workload. However, in the future, the game can be expanded to cover more periods of maths history, making the adventure last longer and being more enjoyable for children as they can play for longer periods of time.

4.5 Hypothesis testing and discussion

The present research attempted to test a digital game designed for primary school students based on research. The game was designed based on a combination of data collected from the literature review, teachers' perceptions of DGBL, and analysis of other classroom games. The empirical experiment was able to partially accept the hypothesis stated in chapter 3. The results suggest the game designed during this research was able to increase the mathematics performance when looking at the whole sample of primary school students that participated in this research. However, the specific classroom analysis suggests that one of the classrooms did not experience any significant difference in mathematics performance after playing the game. The other two classes experienced an increase in the mathematics performance score.

The improvement in the learning outcomes after playing Once Upon a Maths might be related to certain features of the game, such as the interactivity, clear goals and clear feedback (Tang, Hanneghan and El-Rhalibi, 2007). In fact, low-performance students can have better maths outcomes when playing computer games than when doing paper-based exercises (Ku *et al.*, 2014). One of the main novelties of Once Upon a Maths is the use of situated learning and this teaching approach is already well known as an efficient strategy for

mathematics education (Wedge, 1999; Wijers, Jonker and Drijvers, 2010) and researchers suggest that its implementation can be facilitated by the adoption of videogames (Devlin, 2011; Husain, 2011; Zhang and Shang, 2017). To implement the situated learning, *Once Upon a Maths* makes use of the history of Maths as a narrative. The presence of a narrative in serious games is proven to be efficient not only in increasing player engagement and motivation but also to foster learning (Naul and Liu, 2019). The collaborative gameplay used in *Once Upon a Maths* is an element that stimulates students' engagement and is efficient in increasing the learning outcomes, especially when used to develop problem-solving skills (Lazakidou and Retalis, 2010). When looking at the classroom that did not benefit – at least, not significantly – of playing the game to improve their mathematics performance, some aspects should be considered. Classrooms are complex social environments where a large group of people spend hours interacting. The way this net is built is not simple and involves several aspects that can influence how a new member – researchers – or tool – a digital game – is integrated into the situation. According to Burns and Knox (2011), several factors can influence classroom practices, such as time pressure, teacher-student relationships, and the presence of researchers in the classroom. Although research suggests digital games can have a lot of potential as a teaching tool, there are children who do not like to play video games. The social interaction of collaborative play can, depending on the environment, can make children feel under pressure and lead to a loss on the learning benefits of this approach. Cognitive processes and social relations are connected and separating them is quite difficult, and the way students build their social relationships plays a huge importance in their learning outcomes (Patrick, Anderman and Ryan, 2002). Therefore, research considering the social aspects of playing *Once Upon a Maths* should be considered in the future.

The hypothesis also considered that the game could reduce the levels of maths anxiety. Some serious games have been developed as an attempt to overcome anxiety in general (Park, Hu and Huh, 2016; Dekker and Williams, 2017), but there is little research about how games could help children to overcome maths anxiety. The statistical analysis was not able to reject the null hypothesis and suggests that Once Upon a Maths did not reduce the levels of maths anxiety considering the whole group of students. The classroom-specific analysis shows that, in one of the classrooms, there was an increase in the levels of maths anxiety in female students. This was not expected as the game was designed and developed considering elements that, according to previous researches, could make it more engaging for female students. Several reasons should be considered to explain why females tend to have a higher level of maths anxiety than males. Exposure to negative attitudes about maths by role models like parents and teachers, a higher possibility of feeling anxious when seeing another child with maths anxiety, and exposure to gender stereotypes are only a few reasons that might lead females to have higher maths anxiety than males (Beilock *et al.*, 2010; Maloney, Sattizahn and Beilock, 2014; Van Mier, Schleepen and Van den Berg, 2019). The results suggest female students were already significantly more anxious than male students before playing the game. Anxiety is linked to decreased peer acceptance (Erath, Flanagan and Bierman, 2007), which plays an important role for those playing in a social environment such as the classroom.

In general, students demonstrated to be engaged on the gameplay of Once Upon a Maths. The results of the group interview suggested that the idea of transposing the history of maths into a game allowed students to interact and be part of this narrative. In fact, storytelling can be quite powerful for maths education. They make mathematics more

meaningful and provide a context, besides allowing children to connect to other areas of childhood (Casey, Kersh and Young, 2004). The group interviews illustrated how the storytelling and presence of characters helped children to engage with the game. For those that maybe had an idea that maths was a hard science with no fun behind it, playing a game and learning at the same time lead to some kind of confusion – illustrated by the child that declared to hate maths but love the game, or the other one who loved the last part of the game as there were no maths on it. Using the history of maths as a narrative for the game may help students to comprehend that maths is part of our society, making it more natural and less frightening.

4.6 Strengths and limitations of findings

The present work illustrates the implementation of historical-based educational game for mathematics learning in primary school. It evaluates the effects of this game on maths' performance and anxiety, including differences related to gender and specific classroom evaluations. The strengths of the study are on the evaluation of a videogame designed based on previous research studies and analysis of other classroom games already adopted by teachers. For the first time, a digital educational game implemented the real history of mathematics as a game narrative, using storytelling to situate students in the context of mathematics development, being the story aligned with the school curriculum. Situated learning has been used as an attempt to increase learning outcomes in other researches, but there is a lack of studies on how this approach can be adopted on educational games and even less has been discussed on how it can be a tool to reduce levels of maths anxiety. The effects the game played on primary school learning process were assessed through validated tools, mixing quantitative and qualitative measurements. The thesis

provided an empirical research on the effects of a situated learning digital game in primary school, considering not only the learning outcomes but the effects of the game on the maths anxiety aspect. Thus, this research is relevant to researchers in the field of digital games, educational research, and psychology.

Concerning the game design and development, more phases could have been implemented to allow longer experimental stages, which was not possible due to the limit time to implement this PhD research. Results could be more precise with a larger sample of students, and if the experiment lasted longer. Effects related to maths anxiety might require a larger number of gameplay sessions to appear. Considering the game presented a negative effect on the levels of maths anxiety in one of the participant classrooms, an extended study with a larger number of students might be necessary to evaluate if this result would be replicated in other groups. This could clarify, for example, why some of the female students had their levels of anxiety increased when compared to male students.

The results described in this thesis may not reflect the scenario of situated learning mathematics games in general but is exemplified by a specific scenario – the early years of primary school in Ireland. However, the study extends the current knowledge about the Irish educational scenario and might stimulate the growth of the research community in maths games. Future work with a larger sample of students should be done.

5 Conclusion

5.1 Thesis summary

This thesis aimed to evaluate the possible effects of a situated learning videogame on the mathematics learning outcomes and levels of maths anxiety in children from primary school. A game was designed and developed based on a combination of literature review data, teachers perceptions about DGBL, and game features of other classroom games. Teachers perceptions were collected through a survey answered by 714 teachers from 34 countries and showed that the main reasons that influence teachers to adopt games are students' primary language, students' school level, the motivational features of games, the coverage of the official curriculum and if the game is based on pedagogical principles. A framework was also developed to classify educational games adopted by those teachers. This brought details of aspects relevant for the classroom context, like the pedagogical principles of videogames, the genre and the devices used to run these games, covered by 13 categories of classification. The system was designed based on previous taxonomies and research literature in game-based learning and was applied 66 games adopted by the teachers that participated in the survey.

Based on the details collected during this procedure, a situated learning game was developed. Once Upon a Maths is an online adventure 2D game with a narrative based on the history of mathematics. It contains three main phases. The first one covers the maths procedures and concepts from Ancient Egypt. The second covers the maths from Ancient Greece. The third phase focus on the use of maths for computational development in the Modern World. The mechanic of the game consists of interacting with a character from that

time period, who challenges the player, a time traveller, to solve three challenges. If the player succeeds, s/he moves to the next phase to interact with a new character and solve new challenges. The game is designed to cover topics on the curriculum of the first and second classes of primary school level in Ireland. The game was then tested by 88 students from those classes. The experiment lasted 5 weeks, and the visits consisted of 45 minutes to 1 hour per week. The experiment had a pre-test post-test design, and, in the first visit, students answered a pre-maths test with questions related to the concepts covered on the game. They also answered the Modified Abbreviated Math Anxiety Scale (mAMAS), a validated maths test to measure the levels of anxiety on children from primary school. Then, for three weeks, students played the three phases of the game. On the final week, students answered a modified version of the maths test and the same version of mAMAS. The group interview was implemented to collect students' opinions about the game. The data was evaluated by statistical analysis. Results showed that Once Upon a Maths does not affect changing the levels of anxiety when comparing the mAMAS results before and after playing. However, the game significantly increases the levels of anxiety on a specific group of female students. Once Upon a Maths also had an impact on the learning outcomes: an evaluation of the pre and post-maths tests revealed that in two of the three classrooms evaluated, students had an increase in their maths performance.

5.2 Contribution to the body of knowledge

The present thesis aimed to contribute to game-based learning by evaluating the effects of a digital game on mathematics performance and levels of maths anxiety in primary school students. As presented in section 1.5, page 23, this thesis was expected to have

theoretical and practical contributions. This research work's major theoretical contributions consisted in the development and implementation of a classification system for classroom games, considering their game design, technical features, and pedagogical principles. The system structure is based on a literature review, putting together relevant information published by the community. The system was implemented to classify a variety of digital games adopted by teachers in their classrooms, revealing the main features of the most used games. The results support the community in understanding what preferences teachers might have when adopting classroom games and how that can be aligned with their teaching strategies. As games developers are usually not familiar with the classroom environment as an educator would be, the implementation of this system can reveal elements to be considered during the design and deployment of a classroom game. Nevertheless, this classification system can be reused to classify other classroom games, allowing the community to expand the knowledge about what elements are commonly considered when designing educational games.

A minor theoretical contribution was made by collecting information about teachers and their perceptions of classroom games. Demographical data was collected, providing a better understanding of the context where the games evaluated by the classification system are adopted. A variety of factors were considered and their influence on game adoption was measured. Although the teachers who responded the survey might not represent the entire community of educators, this type of study support a better understanding of what might influence teachers to adopt games or not, and the main characteristics of the community of educators who follows a digital game-based learning approach. This can

support other stakeholders to develop guidelines and policies that can help teachers to feel more confident when using a DGBL approach.

The present research also made a major practical contribution by delivering an educational video game that can be played by primary school students. The game is based on the Irish curriculum, which is in line with most of the other countries teaching content. Therefore, the game can be adopted by teachers and support the learning process in the classroom. The game is also underpinned by the pedagogical principles and previous research results, besides proving to be able to increase mathematics performance as shown by the pre and post-test experiment carried out during this research. It is the first time a video game is designed based in the history of mathematics and this can inspire other developers to use this approach in other learning fields. A minor contribution was the analysis of the impact of this game in the levels of mathematics anxiety. The game was designed considering elements that, according to previous research, could make children less anxious when dealing with mathematics activities. However, no significant changes were identified, and new questions can emerge from these results in terms of what other elements of game design might be considered, especially when evaluating the levels of maths anxiety on specific communities, like female students and those with lower performance in mathematics.

5.3 Future work

The present research gives scope to many opportunities of projects in DGBL, maths learning and maths anxiety. In fact, this research progressed to a bigger project that also includes evaluating the power of digital games in reducing the levels of maths anxiety in older children (11-12 years old). The project, entitled Happy Maths, aims to bring maths

games to Irish schools and evaluate their effect in learning outcomes and anxiety. Some game elements could, however, be included in Once Upon a Maths to improve its design.

Further studies should be done to better comprehend the potential of the game on reducing maths anxiety. Although the tools used in this study were well-known and validated, anxiety is a complex state of mind, and physiological measurements, such as heart rate, cortisol secretion and EEG recordings could give a better overview of the students' levels of anxiety (Dowker, Sarkar and Looi, 2016). Specific analysis of the role the game plays on female students' levels of maths anxiety needs to be considered. The pressure of the classroom as a social environment is an important aspect for females, and experiments, where only female students or smaller groups of students plays Once Upon a Maths, could reveal different results.

In the future, improvements in the game design aspect can be done. There is an importance of including a space for the teacher to interact with the game. A dashboard can allow the teacher to monitor student progress, using the game as a formative type of assessment, which means the student will be assessed throughout the entire learning process, and his/her progress and failures will be continuously monitored (Carol, 2002). This type of assessment allows the teacher to adapt their teaching approach to the individual needs of the students. The teacher can generate a detailed report of the whole classroom or each student, also being able to check how the student is progressing when compared to the rest of the classroom. Another interesting aspect of being implemented is an adaptive system. From a computing perspective, an adaptive system can be defined as "an interactive system that adapts its behaviour to individual users based on processes of user model acquisition and application that involve some form of learning, inference, or decision making" (Jameson,

2007, p.434). This is related to the concept of Intelligent Tutoring System (ITS), in which the learner's knowledge, measured while s/he plays the game, for example, is compared to a model of an expert's knowledge through artificial intelligence. The system then runs dynamically adapted to the learner's needs. For Once Upon a Maths, an adaptive system would work to diagnose the player's performance and adapting the game to it. There is also a need, therefore, to develop versions of Once Upon a Maths in other languages in the future.

5.4 Final remarks

This study contributed to a better understanding of the use of situated learning for maths education in the primary school level. It described the planning, design and development of a maths videogame that uses the history of mathematics as a narrative for the adventure. The game described and evaluated during this research study does not intend to be a solution for mathematics education or maths anxiety. There are many aspects involved in learning mathematics and Once Upon a Maths is able to cover only part of them. However, the present study, by following research procedures, contributes to the game-based learning research community and encourages more research in the area.

References

- Accenture (2014) *Powering economic growth; Attracting more young women into science and technology*.
- Ackermann, E. (2001) 'Piaget's Constructivism, Papert's Constructionism: What's the difference?', in *Geneva: Geneva Center in Education*. Geneva, pp. 85–94.
- Adams, E. (2010) *Fundamentals of Game Design*. 2nd edn. Berkeley: New Riders.
- Afari, E. *et al.* (2013) 'Students' perceptions of the learning environment and attitudes in game-based mathematics classrooms', *Learning Environments Research*, 16(1), pp. 131–150. doi: 10.1007/s10984-012-9122-6.
- Al-Washmi, R., Hopkins, G. and Blanchfield, P. (2013) 'Investigating collaborative games to teach mathematics-based problem solving in the classroom', *7th European Conference on Games Based Learning, ECGBL 2013*, 2(February), pp. 617–625.
- Alvarez, J. and Michaud, L. (2008) *Serious Games : Advergaming, edugaming, training and more*, Idate. Montpellier, France: IDATE. doi: 10.1145/1361083.1361093.
- Amory, A. *et al.* (1999) 'The use of computer games as an educational tool: identification of appropriate game types and game elements', *British of Educational Technology*, 30(4), pp. 311–321.
- Anderson, J. R., Reder, L. M. and Simon, H. A. (1996) 'Situated Learning and Education Situated Learning and Education'', *Source: Educational Researcher*, 25(4), pp. 5–11. doi: 10.2307/1176775.

Anderson, L. W. and Krathwohl, D. R. (2001) *A taxonomy for learning, teaching, and assessing: A revision of Bloom's Taxonomy of Educational Objectives*. Longman.

Ang, C. S. *et al.* (2008) 'Linking Pedagogical Theory of Computer Games to Their Usability', *International Journal on E-Learning*, 7(3), pp. 533–558.

Annas, J. (1981) *An Introduction to Plato's Republic*. New York: Oxford University Press.
doi: 10.5840/teachphil19825356.

Annetta, L. A. *et al.* (2009) 'Investigating the impact of video games on high school students' engagement and learning about genetics', *Computers and Education*. Elsevier Ltd, 53(1), pp. 74–85. doi: 10.1016/j.compedu.2008.12.020.

Aremu, A. (2010) 'Using "TRIRACE©" in the Classroom: Perception on Modes and Effectiveness', in Baek, Y. (ed.) *Gaming for Classroom-Based Learning: Digital Role Playing as a Motivator of Study*. New York: IGI Global, pp. 66–83. doi: 10.4018/978-1-61520-713-8.ch004.

Attali, Y. and Arieli-Attali, M. (2015) 'Gamification in assessment: Do points affect test performance?', *Computers and Education*. Elsevier Ltd, 83, pp. 57–63. doi: 10.1016/j.compedu.2014.12.012.

Baek, Y. (2010) *Gaming for Classroom-Based Learning: Digital Role Playing as a Motivator of Study*. New York.

Baek, Y. K. (2008) 'What Hinders Teachers in Using Computer and Video Games in the Classroom? Exploring Factors Inhibiting the Uptake of Computer and Video Games', *CyberPsychology & Behavior*, 11(6), pp. 665–671. doi: 10.1089/cpb.2008.0127.

- Bakar, A., Inal, Y. and Cagiltay, K. (2006) 'Use of Commercial Games for Educational Purposes: Will Today's Teacher Candidates Use them in the Future?', *World Conference on Educational Multimedia, Hypermedia and Telecommunications 2006*, 2006, pp. 1757–1762.
- Bakker, A. and Gravemeijer, K. (2006) 'An historical phenomenology of mean and median', *Educational Studies in Mathematics*, 62(2), pp. 149–168. doi: 10.1007/s10649-006-7099-8.
- Bakker, M., van den Heuvel-Panhuizen, M. and Robitzsch, A. (2015) 'Effects of playing mathematics computer games on primary school students' multiplicative reasoning ability', *Contemporary Educational Psychology*. Elsevier Inc., 40, pp. 55–71. doi: 10.1016/j.cedpsych.2014.09.001.
- Baroody, A. J. *et al.* (2006) 'The Development of Young Children's Early Number and Operation Sense and its Implications for Early Childhood Education', in Olivia N. Saracho, B. S. (ed.) *Handbook of research on the education of young children*. Lawrence Erlbaum Associates Publishers, pp. 187–221. doi: 10.4324/9780203841198.
- Barwell, M. E. (1913) 'The advisability of including some instruction in the school course on the history of mathematics', *The Mathematical Gazette*, 7(104), pp. 72–79.
- Becker, K. (2017) *Choosing and Using Digital Games in the Classroom*. Switzerland: Springer. doi: 10.1007/978-3-319-12223-6.
- Beilock, S. L. *et al.* (2010) 'Female teachers' math anxiety affects girls' math achievement', *Proceedings of the National Academy of Sciences of the United States of America*, 107(5), pp. 1860–1863. doi: 10.1073/pnas.0910967107.

- Bell, R. L., Maeng, J. L. and Binns, I. C. (2013) 'Learning in Context: Technology Integration in a Teacher Preparation Program Informed by Situated Learning Theory', 50(3), pp. 348–379. doi: 10.1002/tea.21075.
- Ben-ari, M. (2010) 'Situated Learning in Computer Science Education', (October 2014), pp. 37–41. doi: 10.1080/08993400412331363823.
- Bergeron, B. (2006) *Developing serious games*. Massachusetts, US: Charles River Media.
- Berns, A., Gonzalez-Pardo, A. and Camacho, D. (2013) 'Game-like language learning in 3-D virtual environments', *Computers and Education*. Elsevier Ltd, 60(1), pp. 210–220. doi: 10.1016/j.compedu.2012.07.001.
- Blonder, R. and Mamlok-Naaman, R. (2019) 'Teaching chemistry through contemporary research versus using a historical approach Abstract':, *Chemistry Teacher International*, (2000), pp. 1–16. doi: 10.1515/cti-2018-0011.
- Bloom, B. S. *et al.* (1956) 'Taxonomy of Educational Objectives: The Classification of Educational Goals: Handbook I Cognitive Domain', *Longmans, Green and Co LTD*, 16, p. 207. doi: 10.1300/J104v03n01_03.
- Bloom, R. and Solotko, J. (2005) 'Using an historical account book as a teaching tool Using an Historical Account Book as a Teaching Tool', *Accounting Education*, 14(3), pp. 239–269. doi: 10.1080/06939280500187316.
- Bottino, R. M. *et al.* (2007) 'Developing strategic and reasoning abilities with computer games at primary school level', 49, pp. 1272–1286. doi: 10.1016/j.compedu.2006.02.003.

Braghirolli, L. F. *et al.* (2016) 'Benefits of educational games as an introductory activity in industrial engineering education', *Computers in Human Behavior*, 58, pp. 315–324. doi: 10.1016/j.chb.2015.12.063.

Bray, A. and Tangney, B. (2017) 'Technology usage in mathematics education research – A systematic review of recent trends', *Computers & Education*. Elsevier Ltd, 114, pp. 255–273. doi: 10.1016/j.compedu.2017.07.004.

Brezovszky, B. *et al.* (2019) 'Effects of a mathematics game-based learning environment on primary school students' adaptive number knowledge', *Computers and Education*. Elsevier Ltd, 128, pp. 63–74. doi: 10.1016/j.compedu.2018.09.011.

Brown, E. and Cairns, P. (2004) 'A grounded investigation of game immersion', *Conference on Human Factors in Computing Systems - Proceedings*, pp. 1297–1300. doi: 10.1145/985921.986048.

Bruce D. Homer, Charles Raffaele, H. H. (2020) 'Game as Playful Learning: Implications of Developmental Theory for Game-Based Learning', in Jan L. Plass, Richard E. Mayer, B. (ed.) *Hanbook of Game-Based Learning*. London: MIT Press, pp. 25–52.

Bruckman, A. (1999) 'Can Educational Be Fun?', in *Game Developer's Conference*. San Jose, pp. 75–79.

Burgoyne, J. G. (2008) 'Learning Theory and the Construction of Self: What Kinds of People do we Create Through the Theories of Learning that we Apply to their Development?', *Individual Differences and Development in Organisations*, (January 2002), pp. 1–16. doi: 10.1002/9780470753392.ch1.

- Burns, A. and Knox, J. (2011) 'Classrooms as Complex Adaptive Systems: A Relational Model.', *Tesl-Ej*, 15(1), pp. 1–25.
- Caleon, I. and Ramanathan, S. (2008) 'From music to physics: The undervalued legacy of pythagoras', *Science and Education*, 17(4), pp. 449–456. doi: 10.1007/s11191-007-9090-x.
- Calvo, M. G. and Eysenck, M. W. (1992) 'Anxiety and Performance: The Processing Efficiency Theory', *Cognition and Emotion*, 6(6), pp. 409–434. doi: 10.1080/02699939208409696.
- Carelli, F. (2011) 'The book of death: Weighing your heart', *London Journal of Primary Care*, (1), pp. 87–88. doi: 10.1080/17571472.2011.11493336.
- Carey, E. *et al.* (2017) 'The modified abbreviated math anxiety scale: A valid and reliable instrument for use with children', *Frontiers in Psychology*, 8(JAN), pp. 1–13. doi: 10.3389/fpsyg.2017.00011.
- Carol, B. (2002) 'The Concept of Formative Assessment', *ERIC Clearinghouse on Assessment and Evaluation College Park MD.*, 1(1), pp. 1–8. doi: ED47026, 2002-10-100.
- Carraher, T. N., Carraher, D. W. and Schliemann, A. D. (1985) 'Mathematics in the streets and in schools', *British Journal of Developmental Psychology*, 3(1), pp. 21–29. doi: 10.1111/j.2044-835x.1985.tb00951.x.
- Cartwright-Hatton, S., McNicol, K. and Doubleday, E. (2006) 'Anxiety in a neglected population: Prevalence of anxiety disorders in pre-adolescent children', *Clinical Psychology Review*, 26(7), pp. 817–833. doi: 10.1016/j.cpr.2005.12.002.

Casey, B., Kersh, J. E. and Young, J. M. (2004) ‘Storytelling sagas: An effective medium for teaching early childhood mathematics’, *Early Childhood Research Quarterly*, 19(1), pp. 167–172. doi: 10.1016/j.ecresq.2004.01.011.

De Castro, M. V. *et al.* (2014) ‘Effect of a virtual environment on the development of mathematical skills in children with dyscalculia’, *PLoS ONE*, 9(7), pp. 1–16. doi: 10.1371/journal.pone.0103354.

Caviola, S. *et al.* (2017) ‘Stress, time pressure, strategy selection and math anxiety in mathematics: A review of the literature’, *Frontiers in Psychology*, 8(SEP), pp. 1–13. doi: 10.3389/fpsyg.2017.01488.

Chang, H. and Beilock, S. L. (2016) ‘The math anxiety-math performance link and its relation to individual and environmental factors: A review of current behavioral and psychophysiological research’, *Current Opinion in Behavioral Sciences*. Elsevier Ltd, 10, pp. 33–38. doi: 10.1016/j.cobeha.2016.04.011.

Chang, K. *et al.* (2012) ‘Computers & Education Embedding game-based problem-solving phase into problem-posing system for mathematics learning’, *Computers & Education*. Elsevier Ltd, 58(2), pp. 775–786. doi: 10.1016/j.compedu.2011.10.002.

Charles, D., Kerr, A. and McNeill, M. (2005) ‘Player-centred game design: Player modelling and adaptive digital games’, in *Proceedings of DiGRA 2005 Conference: Changing Views – Worlds in Play*, pp. 285–298. doi: 10.1.1.97.735.

Charsky, D. and Ressler, W. (2011) ‘“Games are made for fun”: Lessons on the effects of concept maps in the classroom use of computer games’, *Computers and Education*. Elsevier Ltd, 56(3), pp. 604–615. doi: 10.1016/j.compedu.2010.10.001.

Checa-Romero, M. (2016) 'Developing skills in digital contexts: Video games and films as learning tools at primary school', *Games and Culture*, 11(5), pp. 463–488. doi: 10.1177/1555412015569248.

Cheng, M. T., She, H. C. and Annetta, L. A. (2015) 'Game immersion experience: Its hierarchical structure and impact on game-based science learning', *Journal of Computer Assisted Learning*, 31(3), pp. 232–253. doi: 10.1111/jcal.12066.

Chiou, H. (2020) 'The impact of situated learning activities on technology university students ' learning outcome', *Emerald Insight*, 62(6). doi: 10.1108/ET-04-2018-0092.

Chuang, T. and Chen, W. (2007) 'Effect of Computer-Based Video Games on Children : An Experimental Study', (1), pp. 3–7.

Clark, K. *et al.* (2016) 'History of mathematics in mathematics education . Recent developments', in Luis Radford, Fulvia Furinghetti, T. H. (ed.) *Proceedings of the 2016 ICME Satellite Meeting of the International Study Group on the Relations Between the History and Pedagogy of Mathematics*.

Clements, D. H. and Sarama, J. (2007) 'Effects of a preschool mathematics curriculum: Summative reserach on the Building Blocks project', *Journal for Research in Mathematics Education*, 38(2), pp. 136–163. doi: 10.2307/30034954.

Cohen, J. (1988) *Statistical power analysis for the behavioral sciences*. 2nd edn. New York: Lawrence Erlbaum Associates.

Commission, E. (2018) *Commission Working Paper on Key Competencies 2018*. Brussels.

Connolly, T. M. *et al.* (2010) 'A systematic literature review of empirical evidence on computer games and serious games', *Computers and Education*. Elsevier Ltd, 59(2), pp. 661–686. doi: 10.1016/j.compedu.2012.03.004.

Conway, P. (UCC) and Sloane, F. (Arizona S. U. (2006) 'International Trends in Post-Primary Mathematics Education: Perspectives on learning, teaching and assessment', (5), p. 295.

Coughlan, S. (2014) 'Tablet computers in "70% of schools"', *BBC News*, 3 December, pp. 1–13.

Csikszentmihalyi, M. (2000) *Beyond boredom and anxiety*. Wiley.

Dede, C. *et al.* (2005) 'Students' Motivation and Learning of Science in a Multi-User Virtual Environment', in *American Educational Research Association Conference*. Montreal, pp. 1–8.

Dejić, M. and Mihajlović, A. (2014) 'History of Mathematics and Teaching Mathematics', *Teaching Innovations*, 27(3), pp. 15–30.

Dekker, M. R. and Williams, A. D. (2017) 'The Use of User-Centered Participatory Design in Serious Games for Anxiety and Depression', *Games for Health Journal*, 6(6), pp. 327–333. doi: 10.1089/g4h.2017.0058.

DeVellis, R. F. (2017) *Scale Development Theory and Applications (Fourth Edition Robert)*, SAGE Publication. Thousand Oaks: SAGE Publications.

Devine, A. J. (2017) *Cognitive and emotional mathematics learning problems in primary and secondary school students*. University of Cambridge. doi: 10.1111/fcre.12297.

Devlin, K. (2011) *Mathematics Education for a New Era: Video Games as a Medium for Learning*. Natick, Massachusetts: A K Peters.

Dewey, J. (1938) *Experience and Education*. New York: Touchstone.

Dias, E. J. *et al.* (2017) 'Tablets and applications to tell Mathematics History in High School', in *13th International Conference Mobile Learning 2017*, pp. 11–17.

Dickey, M. D. (2006) 'Game design narrative for learning: Appropriating adventure game design narrative devices and techniques for the design of interactive learning environments', *Educational Technology Research and Development*, 54(3), pp. 245–263. doi: 10.1007/s11423-006-8806-y.

Dillon, M. R. *et al.* (2017) 'Intuitive But Not Formal Mathematics', *Science*, 55(July), pp. 47–55.

Djaouti, D., Alvarez, J. and Jessel, J.-P. (2011) 'Classifying serious games: The G/P/S model', *Handbook of research on improving learning and motivation through educational games: Multidisciplinary approaches*, (2005), pp. 118–136. doi: 10.4018/978-1-60960-495-0.ch006.

Dörner, R. *et al.* (2016) *Serious Games - Foundations, Concepts and Practice*. Switzerland: Springer. doi: 10.1007/978-3-319-40612-1.

Dowker, A., Sarkar, A. and Looi, C. Y. (2016) 'Mathematics anxiety: What have we learned in 60 years?', *Frontiers in Psychology*, 7(APR), pp. 1–16. doi: 10.3389/fpsyg.2016.00508.

Drijvers, P. *et al.* (2010) 'Learning and assessing mathematics with and through digital technologies: Introduction to Section 2', in Hoyles, C. and Lagrange, J.-B. (eds) *Mathematics Education and Technology-Rethinking the Terrain*. NY: Springer, p. 8. doi: 10.1007/978-1-4419-0146-0.

Dugard, P. and Todman, J. (1995) 'Analysis of Pre-test-Post-test Control Group Designs in Educational Research', *Educational Psychology*, 15(2), pp. 181–198. doi: 10.1080/0144341950150207.

Van Eck, R. (2006) 'Digital Game-Based Learning: It's Not Just the Digital Natives Who Are Restless', *Educause Review*, 41(2), pp. 16–30. doi: 10.1145/950566.950596.

Eck, R. Van and Dakota, N. (2007) 'Building Artificially Intelligent Learning Games', in Sugumaran, V. (ed.) *Intelligent Information Technologies: Concepts, Methodologies, Tools, and Applications*. Information Science Reference, pp. 271–307.

Einarsdottir, J. (2006) 'From pre-school to primary school: When different contexts meet', *Scandinavian Journal of Educational Research*, 50(2), pp. 165–184. doi: 10.1080/00313830600575965.

Eivers, E. (2019) *Left to their own devices: trends in ICT at primary school level*. Cork: IPPN. doi: 10.1145/2379057.2379105.

Erath, S. A., Flanagan, K. S. and Bierman, K. L. (2007) 'Social anxiety and peer relations in early adolescence: Behavioral and cognitive factors', *Journal of Abnormal Child Psychology*, 35(3), pp. 405–416. doi: 10.1007/s10802-007-9099-2.

Ermi, L. and Mäyrä, F. (2005) 'Fundamental components of the gameplay experience: Analysing immersion', *Proceedings of DiGRA 2005 Conference: Changing Views - Worlds in Play*, (January 2005).

Ernest, P. (1996) 'Popularization: Myths, Massmedia and Modernism', in Bishop, A. J. et al. (eds) *International Handbooks of Mathematics Education*. The Netherlands: Kluwer Academic Publishers, p. 33.

Eseryel, D. et al. (2014) 'International Forum of Educational Technology & Society An Investigation of the Interrelationships between Motivation , Engagement , and Complex Problem Solving in Game-based Learning An Investigation of the Interrelationships between Motivation , Engagem', 17(1).

Essinger, J. (2014) *Ada's Algorithm? How Lord Byron's daughter Ada Lovelace launched the digital age*. London: Melville House.

Farmaki, V. and Paschos, T. (2007) 'Employing genetic "moments" in the history of mathematics in classroom activities', *Educational Studies in Mathematics*, 66(1), pp. 83–106. doi: 10.1007/s10649-006-9056-y.

Fishman, B. et al. (2014) *Empowering Educators: Supporting Student Progress in the Classroom with Digital Games: Part 1 - A National Survey Examining Teachers' Digital Game Use and Formative Assessment Practices*. Michigan.

Freina, L., Bottino, R. and Ferlino, L. (2018) 'Visuospatial Abilities Training with Digital Games in a Primary School', *International Journal of Serious Games*, 5(3), pp. 23–35. doi: 10.17083/ijsg.v5i3.240.

- Frey, B. B. (2018) *The SAGE Encyclopedia of Educational Research Measurement and Evaluation*. Edited by B. B. Frey. California: SAGE Publications.
- Fried, M. N. (2001) ‘Can Mathematics Education and History of Mathematics Coexist?’, *Science & Education*, 10, pp. 391–408.
- Fuegi, J. and Francis, J. (2003) ‘Lovelace & babbage and the creation of the 1843 “Notes”’, *Ada User Journal*, 36(2), pp. 89–98.
- Gee, J. P. (2003) *What video games have to teach us about learning and literacy*. New York: Palgrave Macmillan. doi: 10.1145/950566.950595.
- Gee, J. P. (2004) ‘What Video Games Have to Teach Us about Learning and Literacy’, *Education + Training*, 46(4), pp. 175–178. doi: 10.1108/et.2004.00446dae.002.
- Gee, J. P. (2008) ‘Learning and Games’, in Tekinbaş, K. S. (ed.) *The Ecology of Games: Connecting Youth, Games, and Learning*. Cambridge: MIT Press, p. 20.
- Geist, E. (2019) ‘Reducing Anxiety in Children: Creating Emotionally Safe Places for Children to Learn’, *Archives in Neurology & Neuroscience*, 5(2), pp. 9–10. doi: 10.33552/ann.2019.05.000610.
- Giannakos, M. N. *et al.* (2012) “‘This game is girly!’ Perceived enjoyment and student acceptance of edutainment’, *Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, 7516 LNCS(246016), pp. 89–98. doi: 10.1007/978-3-642-33466-5_10.

Giannakos, M. N. (2013) 'Enjoy and learn with educational games: Examining factors affecting learning performance', *Computers and Education*. Elsevier Ltd, 68(246016), pp. 429–439. doi: 10.1016/j.compedu.2013.06.005.

Gil-Doménech, D. and Berbegal-Mirabent, J. (2017) 'Stimulating students' engagement in mathematics courses in non-STEM academic programmes: A game-based learning', *Innovations in Education and Teaching International*. Routledge, 56(1), pp. 57–65. doi: 10.1080/14703297.2017.1330159.

Ginsburg, H. P. *et al.* (2006) 'Mathematical Thinking and Learning', *Blackwell Handbook of Early Childhood Development*, pp. 208–229. doi: 10.1002/9780470757703.ch11.

Ginsburg, H. P., Lee, J. S. and Boyd, J. S. (2008) *Mathematics Education for Young Children: What It is and How to Promote It*, Society for Research in Child Development.

Gros, B. (2007) 'Digital Games in Education: The Design of Games-Based Learning Environments', *Journal of Research on Technology in Education*, 40(1), pp. 23–38.

Gros, B. (2016) 'Game Dimensions and Pedagogical Dimension in Serious Games', in Zheng, R. and Gardner, M. K. (eds) *Handbook of Research on Serious Games for Educational Applications*. Hershey: IGI Global, p. 495. doi: 10.4018/978-1-5225-0513-6.ch019.

De Grove, F., Bourgonjon, J. and Van Looy, J. (2012) 'Digital games in the classroom? A contextual approach to teachers' adoption intention of digital games in formal education', *Computers in Human Behavior*. Elsevier Ltd, 28(6), pp. 2023–2033. doi: 10.1016/j.chb.2012.05.021.

Gupta, D. and Kim, B. (2014) 'Connecting Aesthetics and Engagement in Game Based Learning', *Proceedings of the IDEAS: Rising to Challenge Conference*, pp. 81–90.

Hainey, T. *et al.* (2016) 'A systematic literature review of games-based learning empirical evidence in primary education', *Computers and Education*. Elsevier Ltd, 102(January 2004), pp. 202–223. doi: 10.1016/j.compedu.2016.09.001.

Hamlen, K. R. (2017) 'General Problem- Solving Styles and Approaches in Video Games'. doi: 10.1177/0735633117729221.

Harris, P. and Walling, D. (2013) 'Merging Art and Science with Educational Technology', *Techtrends*, 57(5), pp. 35–42.

Hartmann, T. and Klimmt, C. (2006) 'Gender and computer games: Exploring females' dislikes', *Journal of Computer-Mediated Communication*, 11(4), pp. 910–931. doi: 10.1111/j.1083-6101.2006.00301.x.

Harzing, A.-W., Reiche, B. S. and Pudenko, M. (2013) 'Challenges in international survey research: a review with illustrations and suggested solutions for best practice', *European J. International Management*, 7(1), pp. 112–134.

Hasibuan, Z. A. *et al.* (2011) 'Preservation of Cultural Heritage and Natural History through Game Based Learning', *International Journal of Machine Learning and Computing*, 1(5), pp. 2–7.

Henderson, D. P. S. (2019) *Exploring the Impact of a Mindfulness-Based Intervention in Relation to Primary School Children's Mathematics Anxiety*. University of Exeter.

Henslee, A. and Klein, B. (2017) 'Using Brief Guided Imagery to Reduce Math Anxiety and Improve Math Performance: A Pilot Study', *Journal of STEM Education*, 18(4), p. 32.

Herrington, J. and Oliver, R. (1995) 'Critical Characteristics of Situated Learning: Implications for the Instructional Design of Multimedia', in *ASCILITE 1995 Conference*. Melbourne, pp. 253–262.

Herz, J. C. (1997) *Joystick nation, The effects of brief mindfulness intervention on acute pain experience: An examination of individual difference*. Canada: Little, Brown and Company. doi: 10.1017/CBO9781107415324.004.

Hobbs, L. and Davis, R. (2012) 'Narrative Pedagogies in Science, Mathematics and Technology', *Research in Science Education*, (June). doi: 10.1007/s11165-012-9302-5.

Hong, Y. and Chen, P. (2016) 'The application of HPM video clips in mathematical teaching in middle school : Teaching the application of linear equation with one unknown To cite this version : HAL Id : hal-01349270 THE APPLICATION OF HPM VIDEO CLIPS IN'.

Hopko, D. R. *et al.* (2003) 'The Abbreviated Math Anxiety Scale (AMAS): Construction , Validity , and Reliability', *Assessment*, 10(2), pp. 178–182. doi: 10.1177/1073191103252351.

Hou, H. T. (2015) 'Integrating cluster and sequential analysis to explore learners' flow and behavioral patterns in a simulation game with situated-learning context for science courses: A video-based process exploration', *Computers in Human Behavior*. Elsevier Ltd, 48, pp. 424–435. doi: 10.1016/j.chb.2015.02.010.

Hou, H. T. and Li, M. C. (2014) 'Evaluating multiple aspects of a digital educational problem-solving-based adventure game', *Computers in Human Behavior*. Elsevier Ltd, 30, pp. 29–38. doi: 10.1016/j.chb.2013.07.052.

Hunsley, J. and Flessati, S. L. (1988) 'Gender and mathematics anxiety: The role of math-related experiences and opinions', *Anxiety Research*, 1(3), pp. 215–224. doi: 10.1080/08917778808248720.

Husain, L. (2011) *Getting Serious about Math: Serious Game Design Framework & an Example of a Math Educational Game*. Lund University.

Hussein, M. H. *et al.* (2019) 'Effects of Digital Game-Based Learning on Elementary Science Learning: A Systematic Review', *IEEE Access*. IEEE, 7, pp. 62465–62478. doi: 10.1109/ACCESS.2019.2916324.

Hwang, G. J., Wu, P. H. and Chen, C. C. (2012) 'An online game approach for improving students' learning performance in web-based problem-solving activities', *Computers and Education*. Elsevier Ltd, 59(4), pp. 1246–1256. doi: 10.1016/j.compedu.2012.05.009.

Inan, F. A. *et al.* (2010) 'Pattern of classroom activities during students' use of computers: Relations between instructional strategies and computer applications', *Teaching and Teacher Education*. Elsevier Ltd, 26(3), pp. 540–546. doi: 10.1016/j.tate.2009.06.017.

Ireland, G. of (1999) 'Mathematics curriculum'. Dublin: The stationery office, p. 134.

Iten, N. and Petko, D. (2016) 'Learning with serious games: Is fun playing the game a predictor of learning success?', *British Journal of Educational Technology*, 47(1), pp. 151–163. doi: 10.1111/bjet.12226.

Jameson, A. (2007) 'Adaptive Interfaces and Agents', in Sears, A. and Jacko, J. (eds) *The Human-Computer Interaction Handbook Fundamentals, Evolving Technologies, and Emerging Applications*. 2nd edn. New York: Laurence Erlbaum Associates, pp. 433–458. doi: 10.1201/9781410615862.ch22.

Jansen, B. R. J. *et al.* (2013) 'The influence of experiencing success in math on math anxiety, perceived math competence, and math performance', *Learning and Individual Differences*. Elsevier Inc., 24, pp. 190–197. doi: 10.1016/j.lindif.2012.12.014.

Javora, O. *et al.* (2019) 'Children like it more but don't learn more: Effects of esthetic visual design in educational games', *British Journal of Educational Technology*, 50(4). doi: 10.1111/bjet.12701.

Jegers, K. (2007) 'Pervasive Game Flow Understanding Player.pdf', *Computers in Entertainment (CIE)*, 5(1), pp. 1–11. doi: 10.1145/1219124.1219133.

Jennett, C. *et al.* (2008) 'Measuring and defining the experience of immersion in games', *Int. J. Human-Computer Studies*, 66, pp. 641–661. doi: 10.1016/j.ijhcs.2008.04.004.

Ju, E. and Wagner, C. (1997) 'Personal computer adventure games', *The Data Base for Advances in Information Systems*, 28(2), pp. 78–92. doi: 10.1145/264701.264707.

Karaduman, G. B. (2010a) 'A sample study for classroom teachers addressing the importance of utilizing history of math in math education', *Procedia - Social and Behavioral Sciences*, 2(2), pp. 2689–2693. doi: 10.1016/j.sbspro.2010.03.397.

Karaduman, G. B. (2010b) 'A sample study for classroom teachers addressing the importance of utilizing history of math in math education', *Procedia - Social and Behavioral Sciences*, 2(2), pp. 2689–2693. doi: 10.1016/j.sbspro.2010.03.397.

Kavanagh, L. *et al.* (2015) *The 2014 National Assessments of English Reading and Mathematics Volume II: Context Report*. Dublin.

Ke, F. and Building, K. (2006) 'Classroom Goal Structures for Educational Math Game Application', pp. 314–320.

Kebritchi, M. and Hirumi, A. (2008) 'Examining the pedagogical foundations of modern educational computer games', *Computers and Education*, 51(4), pp. 1729–1743. doi: 10.1016/j.compedu.2008.05.004.

Kebritchi, M., Hirumi, A. and Bai, H. (2010) 'The effects of modern mathematics computer games on mathematics achievement and class motivation', *Computers and Education*. Elsevier Ltd, 55(2), pp. 427–443. doi: 10.1016/j.compedu.2010.02.007.

Kelleher, C. and Weir, S. (2016) 'Class Size and Student-Teacher Ratio At Primary Level in Ireland and Other Oecd Countries', *The Irish Journal of Education*, pp. 39–60.

Kelly, H. *et al.* (2007) 'How to build serious games', *Communications of the ACM*, 50(7), pp. 45–49.

Kenny, R. F. and McDaniel, R. (2011) 'The role teachers' expectations and value assessments of video games play in their adopting and integrating them into their classrooms', *British Journal of Educational Technology*, 42(2), pp. 197–213. doi: 10.1111/j.1467-8535.2009.01007.x.

Khan, A., Ahmad, F. H. and Malik, M. M. (2017) 'Use of digital game based learning and gamification in secondary school science: The effect on student engagement, learning and gender difference', *Education and Information Technologies*. Education and Information Technologies, 22(6), pp. 2767–2804. doi: 10.1007/s10639-017-9622-1.

- Kiili, K., Moeller, K. and Ninaus, M. (2018) 'Evaluating a Game-Based Training of Rational Number Understanding - In-Game Metrics as Learning Indicators (under Review)', *Computers & Education*. Elsevier, 120(January), pp. 13–28. doi: 10.1016/j.compedu.2018.01.012.
- Kim, B., Park, H. and Baek, Y. (2009) 'Not just fun, but serious strategies: Using meta-cognitive strategies in game-based learning', *Computers and Education*. Elsevier Ltd, 52(4), pp. 800–810. doi: 10.1016/j.compedu.2008.12.004.
- Kirkpatrick, G. (2007) 'Between Art and Gameness: Critical Theory and Computer Game Aesthetics', *Thesis Eleven*, 89(1), pp. 74–93. doi: 10.1177/0725513607076134.
- Kirriemuir, J. and McFarlane, A. (2004) *Literature Review in Games and Learning, FutureLab Series*. Bristol. doi: 10.1111/j.1541-0072.1974.tb01308.x.
- Knowles, M. S., Holton, E. F. and Swanson, R. A. (2005) *The adult learner*. 6th edn. San Diego: Elsevier.
- Koh, E. *et al.* (2012) 'Teacher Perceptions of Games in Singapore Schools', *Simulation & Gaming*, 43(1), pp. 51–66. doi: 10.1177/1046878111401839.
- Kolb, A. Y. and Kolb, D. A. (2005) 'Learning styles and learning spaces: Enhancing experiential learning in higher education', *Academy of Management Learning and Education*, 4(2), pp. 193–212. doi: 10.5465/AMLE.2005.17268566.
- Kolb, D. (1984) *Experiential Learning: Experience As The Source Of Learning And Development*. Englewood Cliffs, NJ: Prentice Hall.

Kool, M. (2003) 'An extra student in your classroom: How the history of Mathematics can enrich interactive mathematical discussions at primary school', *Mathematics in School*, pp. 19–22.

Ku, O. *et al.* (2014) 'The effects of game-based learning on mathematical confidence and performance: High ability vs. low ability', *Educational Technology and Society*, 17(3).

Kuiper, E. and de Pater-Sneep, M. (2014) 'Student perceptions of drill-and-practice mathematics software in primary education', *Mathematics Education Research Journal*, 26(2), pp. 215–236. doi: 10.1007/s13394-013-0088-1.

Lane, C., Stynes, M. and O'Donoghue, J. (2014) 'The image of mathematics held by Irish post-primary students', *International Journal of Mathematical Education in Science and Technology*, 45(6), pp. 879–891. doi: 10.1080/0020739X.2014.884648.

Lave, J. and Wenger, E. (1991) *Situated Learning Legitimate Peripheral Participation*, Cambridge University Press.

Lay, A.-N. and Osman, K. (2018) 'Developing 21 st Century Chemistry Learning through Designing Digital To cite this article : Developing 21 st Century Chemistry Learning through Designing Digital Games', *Journal of Education in Science, Environment and Health Volume*, 4(1). doi: 10.21891/jeseh.387499.

Lazakidou, G. and Retalis, S. (2010) 'Using computer supported collaborative learning strategies for helping students acquire self-regulated problem-solving skills in mathematics', *Computers and Education*. Elsevier Ltd, 54(1), pp. 3–13. doi: 10.1016/j.compedu.2009.02.020.

Lehtinen, E. *et al.* (2017) ‘Cultivating mathematical skills: from drill-and-practice to deliberate practice’, *ZDM - Mathematics Education*. Springer Berlin Heidelberg, 49(4), pp. 625–636. doi: 10.1007/s11858-017-0856-6.

Lestari, I. and Ratnaningsih, T. (2016) ‘The Effects of Modified Games on the Development of Gross Motor Skill in Preschoolers’, *International Journal of Evaluation and Research in Education (IJERE)*, 5(3), p. 216. doi: 10.11591/ijere.v5i3.4542.

Lester, J. C. *et al.* (2014) ‘Designing game-based learning environments for elementary science education: A narrative-centered learning perspective’, *Information Sciences*. Elsevier Inc., 264, pp. 4–18. doi: 10.1016/j.ins.2013.09.005.

Lim, C. S., Tang, K. N. and Kor, L. K. (2012) ‘Drill and Practice in Learning (and Beyond)’, in Seel, N. (ed.) *Encyclopedia of the Sciences of Learning*. Springer, pp. 1040–1042. doi: 10.1007/978-1-4419-1428-6_706.

Lo, J. J. *et al.* (2008) ‘Developing a digital game-based situated learning system for ocean ecology’, *Transactions on Edutainment*, 5080 LNCS(2006), pp. 51–61. doi: 10.1007/978-3-540-69744-2_5.

Logan, T. and Woodland, K. (2015) ‘Digital Games and Mathematics Learning: The State of Play’, in Lowrie, T. and Jorgensen, R. (eds) *Digital Games and Mathematics Learning - Potential, Promises and Pitfalls*. Netherlands: Springer, pp. 277–304. doi: 10.1007/978-94-017-9517-3.

De Lope, R. P. and Medina-Medina, N. (2017) ‘A Comprehensive Taxonomy for Serious Games’, *Journal of Educational Computing Research*, 55(5), pp. 629–672. doi: 10.1177/0735633116681301.

- Lowrie, T. and Jorgensen, R. (2015) ‘Digital Games and Learning: What’s New is Already Old?’, in Lowrie, T. and Jorgensen, R. (eds) *Digital Games and Mathematics Learning - Potential, Promises and Pitfalls*. The Netherlands: Springer, p. 9.
- Luttenberger, S., Wimmer, S. and Paechter, M. (2018) ‘Spotlight on math anxiety’, *Psychology Research and Behavior Management*, 11, pp. 311–322. doi: 10.2147/PRBM.S141421.
- Ma, X. (1999) ‘A meta-analysis of the relationship between anxiety toward mathematics and achievement in mathematics’, *Journal for Research in Mathematics Education*, 30(5), pp. 520–540. doi: 10.2307/749772.
- Ma, X. and Xu, J. (2004) ‘The causal ordering of mathematics anxiety and mathematics achievement: A longitudinal panel analysis’, *Journal of Adolescence*, 27(2), pp. 165–179. doi: 10.1016/j.adolescence.2003.11.003.
- Madjar, N. *et al.* (2018) ‘Predictors of developing mathematics anxiety among middle-school students: A 2-year prospective study’, *International Journal of Psychology*, 53(6), pp. 426–432. doi: 10.1002/ijop.12403.
- Magliaro, J. and Ezeife, A. (2008) ‘Canadian Journal of Learning and Technology / La revue canadienne de l’ apprentissage et de la Classroom’, 33(3), pp. 1–9.
- Major, L., Haßler, B. and Hennessy, S. (2017) ‘Tablet Use in Schools: Impact, Affordances and Considerations’, in Marcus-Quinn, A. and Hourigan, T. (eds) *Handbook on Digital Learning for K-12 Schools*. Springer, pp. 115–128. doi: 10.1007/978-3-319-33808-8.

Maloney, E. A. *et al.* (2015) 'Intergenerational effects of parents' math anxiety on children's math achievement and anxiety', *Psychological Science*, 26(9), pp. 1480–1488. doi: 10.1177/0956797615592630.

Maloney, E. A., Sattizahn, J. R. and Beilock, S. L. (2014) 'Anxiety and cognition', *Wiley Interdisciplinary Reviews: Cognitive Science*, 5(4), pp. 403–411. doi: 10.1002/wcs.1299.

Maloney, E. A., Schaeffer, M. W. and Beilock, S. L. (2013) 'Mathematics anxiety and stereotype threat: Shared mechanisms, negative consequences and promising interventions', *Research in Mathematics Education*, 15(2), pp. 115–128. doi: 10.1080/14794802.2013.797744.

Mamlok-Naaman, R. *et al.* (2004) 'Mamlok-Naaman , R ., Ben-Zvi , R ., Hofstein , A ., Menis , J ., & Erduran , S . (2005). Influencing Students ' Attitudes towards Science by exposing them to a Historical Approach . Internatio ...', *International Journal of Science and Mathematics Education*, 3.

Mammarella, I. C. *et al.* (2018) 'Anxiety profiles and protective factors: A latent profile analysis in children', *Personality and Individual Differences*, 124(October 2017), pp. 201–208. doi: 10.1016/j.paid.2017.12.017.

Manwell, J. L. and Sullivan, C. R. (2013) 'History and Technology : Integrating STEM Content into Elementary Classrooms Through History-Based Themes', in *3rd IEEE Integrated STEM Education Conference*. IEEE, pp. 1–5.

Di Martino, P. and Zan, R. (2010) "“Me and maths”": Towards a definition of attitude grounded on students' narratives', *Journal of Mathematics Teacher Education*, 13(1), pp. 27–48. doi: 10.1007/s10857-009-9134-z.

- Mazzone, L. *et al.* (2007) 'The role of anxiety symptoms in school performance in a community sample of children and adolescents', *BMC Public Health*, 7(December). doi: 10.1186/1471-2458-7-347.
- McLaren, B. M. *et al.* (2017) 'A Computer-Based Game that Promotes Mathematics Learning More than a Conventional Approach', *International Journal of Game-Based Learning*, 7(1), pp. 36–56. doi: 10.4018/IJGBL.2017010103.
- McMullan, M., Jones, R. and Lea, S. (2012) 'Math anxiety, self-efficacy, and ability in British undergraduate nursing students', *Research in Nursing and Health*, 35(2), pp. 178–186. doi: 10.1002/nur.21460.
- Mcquiggan, S. W. *et al.* (2008) 'Story-Based Learning : The Impact of Narrative on Learning Experiences and Outcomes', pp. 530–539.
- Mendonça, R. L., Mustaro, P. N. and Mackenzie, U. P. (2012) 'Immersion : Immersion and Emotion in Digital Games', pp. 102–113.
- Meyer, B. (2012) 'Game-based language learning for pre-school children: A design perspective', *Proceedings of the European Conference on Games-based Learning*, 11(1), pp. 39–48.
- Michael, D. R. and Chen, S. L. (2006) 'Serious Games: Games That Educate, Train, and Inform', *Education*, pp. 1–95. doi: 10.1021/la104669k.
- Van Mier, H. I., Schleepen, T. M. J. and Van den Berg, F. C. G. (2019) 'Gender differences regarding the impact of math anxiety on arithmetic performance in second and fourth graders', *Frontiers in Psychology*, 9(JAN), pp. 1–13. doi: 10.3389/fpsyg.2018.02690.

Mihas, P. and Andreadis, P. (2005) 'A Historical Approach to the Teaching of the Linear Propagation of Light , Shadows and Pinhole Cameras', pp. 675–697. doi: 10.1007/s11191-005-1793-2.

Miller, D. J. and 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), pp. 242–255. doi: 10.1111/j.1467-8535.2008.00918.x.

Miller, G. A. and Gildea, P. M. (1987) 'How children learn words', *Scientific American*, pp. 94–99.

Miller, L. *et al.* (2002) 'Teaching Neuroscience through Web Adventures : Adolescents Reconstruct the History and Science of Opioids', pp. 16–21.

Millstone, J. (2012) *Teacher Attitudes about Digital Games in the Classroom, the Joan Ganz Cooney Center at Seasmeworkshop*.

Moreno, R. and Mayer, R. E. (2007) *Interactive multimedia learning environments*, *Educational Psychology Review*. doi: 10.1145/2615726.2615730.

Mullis, I. V. S. *et al.* (2015) *Trends in International Mathematics and Science Study, Distribution of Science Achievement*.

Naul, E. and Liu, M. (2019) 'Why Story Matters: A Review of Narrative in Serious Games', *Journal of Educational Computing Research*, p. 21. doi: 10.1177/0735633119859904.

Nazar, B. (2017) 'Examining the Symbolic Meaning of Colors', (November).

Nazleen, S., Rabu, A. and Talib, Z. (2015) 'The Effects of Digital Game-based Learning on Primary School Students The Effects of Digital Game-based Learning on Primary School Students' English Vocabulary Achievement and Acceptance', *Innovative Teaching and Learning Journal*, 1(1), pp. 61–74.

NCCA (2020) *Draft Primary Curriculum Framework For consultation*. Dublin.

Nelson, J. M. and Harwood, H. (2011) 'Learning disabilities and anxiety: A meta-analysis', *Journal of Learning Disabilities*, 44(1), pp. 3–17. doi: 10.1177/0022219409359939.

Neuwirth, L. S., Dacius Jr, T. F. and Mukherji, B. R. (2018) 'Teaching Neuroanatomy Through a Historical Context', 16(2), pp. 26–31.

Nolan, J. and McBride, M. (2014) 'Beyond gamification: reconceptualizing game-based learning in early childhood environments', *Information Communication and Society*, 17(5), pp. 594–608. doi: 10.1080/1369118X.2013.808365.

Noss, R. and Hoyles, C. (1996) *Windows on mathematical meanings : learning cultures and computers*, *Mathematics education library*. doi: 10.1007/978-94-009-1696-8.

Núñez Castellar, E. *et al.* (2015) 'Cognitive abilities, digital games and arithmetic performance enhancement: A study comparing the effects of a math game and paper exercises', *Computers and Education*, 85, pp. 123–133. doi: 10.1016/j.compedu.2014.12.021.

O'Leary, M. *et al.* (2019) *Standardised testing in English reading and mathematics in the Irish primary school: A survey of Irish primary teachers*. Dublin.

Obikwelu, C. and Read, J. C. (2012) 'The Serious Game Constructivist Framework for

Children's Learning', *Procedia Computer Science*, 15(0), pp. 32–37. doi: 10.1016/j.procs.2012.10.055.

Orey, M. (2010) *Emerging Perspectives on Learning, Teaching, and Technology*. Zurich. doi: 10.4324/9780203422090.

Orhan Göksün, D. and Gürsoy, G. (2019) 'Comparing success and engagement in gamified learning experiences via Kahoot and Quizizz', *Computers and Education*. Elsevier, 135(March), pp. 15–29. doi: 10.1016/j.compedu.2019.02.015.

Papert, S. and Harel, I. (1991) 'Situating Constructionism', in Papert, S. and Harel, I. (eds) *Constructionism*. Westport: Ablex Publishing, pp. 1–11. doi: 10.1111/1467-9752.00269.

Pappano, L. (2013) 'Changing the face of math', *Harvard Education Letter*, 29(Number 3), pp. 1–3.

Park, T., Hu, T. and Huh, J. (2016) 'Plant-based games for anxiety reduction', *CHI PLAY 2016 - Proceedings of the 2016 Annual Symposium on Computer-Human Interaction in Play*, pp. 199–204. doi: 10.1145/2967934.2968094.

Patrick, H., Anderman, L. H. and Ryan, A. M. (2002) 'Social motivation and the classroom social environment', in *Goals, goal structures, and patterns of adaptive learning.*, pp. 85–108.

Patten, B., Sánchez, I. A. and Tangney, B. (2006) 'Designing collaborative, constructionist and contextual applications for handheld devices', *Computers and Education*, 46(3), pp. 294–308. doi: 10.1016/j.compedu.2005.11.011.

Peirce, N. (2013) 'Digital Game-based Learning for Early Childhood A State of the Art Report'.

Plass, J. L. *et al.* (2013) 'The impact of individual, competitive, and collaborative mathematics game play on learning, performance, and motivation', *Journal of Educational Psychology*, 105(4), pp. 1050–1066. doi: 10.1037/a0032688.

Plump, C. M. and LaRosa, J. (2017) 'Using Kahoot! in the Classroom to Create Engagement and Active Learning: A Game-Based Technology Solution for eLearning Novices', *Management Teaching Review*, 2(2), pp. 151–158. doi: 10.1177/2379298116689783.

Pratama, L. D. and Setyaningrum, W. (2018) 'GBL in Math Problem Solving: Is it Effective?', *International Journal of Interactive Mobile Technologies (iJIM)*, 12(6), pp. 101–111.

Prensky, M. (2001) *Digital Game-Based Learning*. New York: McGraw-Hill.

Pruet, P., Ang, C. S. and Farzin, D. (2016) 'Understanding tablet computer usage among primary school students in underdeveloped areas: Students' technology experience, learning styles and attitudes', *Computers in Human Behavior*. Elsevier Ltd, 55, pp. 1131–1144. doi: 10.1016/j.chb.2014.09.063.

PuenteDura, R. (2009) *Game and Learn : An Introduction to Educational Gaming*. Available at: http://hippasus.com/resources/gameandlearn/slides/14_TPCK_SAMR_AndGames.pdf.

Rambli, D. R. A., Matcha, W. and Sulaiman, S. (2013) 'Fun learning with AR alphabet book for preschool children', *Procedia Computer Science*. Elsevier Masson SAS, 25, pp. 211–219. doi: 10.1016/j.procs.2013.11.026.

Ramirez, G. *et al.* (2013) 'Math Anxiety, Working Memory, and Math Achievement in Early Elementary School', *Journal of Cognition and Development*, 14(2), pp. 187–202. doi: 10.1080/15248372.2012.664593.

Ramirez, G., Shaw, S. T. and Maloney, E. A. (2018) 'Math Anxiety: Past Research, Promising Interventions, and a New Interpretation Framework', *Educational Psychologist*, 53(3), pp. 145–164. doi: 10.1080/00461520.2018.1447384.

Ratan, R. and Ritterfeld, U. (2009) 'Classifying Serious Games', *Serious games: Mechanisms and effects*, (January), pp. 10–24. doi: 10.4324/9780203891650.

Reese, H. W. (2011) 'The learning-by-doing principle.', *Behavioral Development Bulletin*, 17(1), pp. 1–19. doi: 10.1037/h0100597.

Reyes, J. D. C. (2019) 'Increasing Self-efficacy and Alleviating Anxiety using Touch Math and Instructional Games: An Intervention for Low Performing Seventh Graders', *Journal of Humanities and Education Development*, 1(2), pp. 59–74. doi: 10.22161/jhed.1.2.2.

Robertson, D. and Miller, D. (2009) 'Learning gains from using games consoles in primary classrooms: a randomized controlled study', *Procedia - Social and Behavioral Sciences*, 1(1), pp. 1641–1644. doi: 10.1016/j.sbspro.2009.01.289.

Rodrigues, M. and Simeão Carvalho, P. (2013) 'Teaching physics with angry birds: Exploring the kinematics and dynamics of the game', *Physics Education*, 48(4), pp. 431–437. doi: 10.1088/0031-9120/48/4/431.

Romero, M. (2019) 'Main text Introduction Digital games among secondary learners Educational Serious Games (ESG) in secondary schools', in Tatnall, A. (ed.) *Encyclopedia of Education and Information Technologies*. Springer.

Ronimus, M. *et al.* (2014) ‘Children’s engagement during digital game-based learning of reading: The effects of time, rewards, and challenge’, *Computers and Education*. Elsevier Ltd, 71, pp. 237–246. doi: 10.1016/j.compedu.2013.10.008.

Rubinsten, O., Bialik, N. and Solar, Y. (2012) ‘Exploring the relationship between math anxiety and gender through implicit measurement’, *Frontiers in Human Neuroscience*, 6(SEPTEMBER), pp. 1–11. doi: 10.3389/fnhum.2012.00279.

Sampayo-Vargas, S. *et al.* (2013) ‘The effectiveness of adaptive difficulty adjustments on students’ motivation and learning in an educational computer game’, *Computers and Education*. Elsevier Ltd, 69, pp. 452–462. doi: 10.1016/j.compedu.2013.07.004.

Samuel, T. S. and Warner, J. (2019) “‘I Can Math!’: Reducing Math Anxiety and Increasing Math Self-Efficacy Using a Mindfulness and Growth Mindset-Based Intervention in First-Year Students’, *Community College Journal of Research and Practice*. Routledge, 00(00), pp. 1–18. doi: 10.1080/10668926.2019.1666063.

Sánchez-Mena, A., Martí-Parreño, J. and Aldás-Manzano, J. (2018) ‘Teachers’ intention to use educational video games: The moderating role of gender and age’, *Innovations in Education and Teaching International*. Routledge, 3297, pp. 1–12. doi: 10.1080/14703297.2018.1433547.

Sánchez, J. and Olivares, R. (2011) ‘Problem solving and collaboration using mobile serious games’, *Computers and Education*. Elsevier Ltd, 57(3), pp. 1943–1952. doi: 10.1016/j.compedu.2011.04.012.

Sandford, R. *et al.* (2006) ‘Teaching with Games’, *Computer Educationstaffordcomputer Education Group*, 112, p. 12.

Schell, J. (2014) *The Art of Game Design, Second Edition*. Boca Raton: Taylor & Francis Group.

Seyda Gul. and Yesilyurt, S. (2015) 'The Effect of Computer Assisted Instruction on Achievement and Attitude of Primary School Students.', *International Online Journal of Educational Sciences*, 7(1), pp. 97–109. doi: 10.15345/iojes.2014.03.002.

Shaker, N., Yannakakis, G. N. and Togelius, J. (2010) 'Towards Automatic Personalized Content Generation for Platform Games.', in *Proceedings of the 6th AAAI Conference on Artificial Intelligence and Interactive Digital Entertainment*, pp. 63–68. doi: 10.1.1.175.3536.

Sharp, A. (2012) 'Humanistic approaches to learning', in Seel, N. (ed.) *Encyclopedia of the Sciences of Learning*. Springer.

Siegler, R. S. *et al.* (2012) 'Early Predictors of High School Mathematics Achievement', *Psychological Science*, 23(7), pp. 691–697. doi: 10.1177/0956797612440101.

Simões, J., Redondo, R. D. and Vilas, A. F. (2013) 'A social gamification framework for a K-6 learning platform', *Computers in Human Behavior*, 29(2), pp. 345–353. doi: 10.1016/j.chb.2012.06.007.

Skemp, R. R. (1989) *Mathematics in the primary school*. doi: 10.4324/9780203403891.

Skills, D. of E. and (2015) *Digital Strategy for Schools 2015-2020: Enhancing Teaching, learning and assessment*. Dublin.

Slussareff, M. *et al.* (2013) 'Games for Learning', *Entertainment Computing and Serious Games*, 91(4), pp. 16–20. doi: 10.1007/978-3-319-46152-6_9.

- Smarkola, C. (2008) 'Developmentally Responsive Technology-Literacy Use in Education: Are Teachers Helping Students Meet Grade-Level National Technology Standards?', *Journal of Educational Computing Research*, 38(4), pp. 387–409. doi: 10.2190/EC.38.4.b.
- Smyth, E. (2017) *Growing Up in Ireland OFF TO A GOOD START? Primary School Experiences and the Transition to Second-Level Education*. Dublin.
- Squire, K. (2006) 'From Content to Context: Videogames as Designed Experience', *Educational Researcher*, 35(8), pp. 19–29. doi: 10.3102/0013189X035008019.
- Squire, K., Barab, S. and Technology, I. S. (1991) 'Replaying History : Engaging Urban Underserved Students in Learning World History Through Computer Simulation Games', pp. 505–512.
- Stoet, G. *et al.* (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), pp. 1–24. doi: 10.1371/journal.pone.0153857.
- Sudarmilah, E. *et al.* (2013) 'Tech review: Game platform for upgrading counting ability on preschool children', *Proceedings - 2013 International Conference on Information Technology and Electrical Engineering: 'Intelligent and Green Technologies for Sustainable Development'*, *ICITEE 2013*, pp. 226–231. doi: 10.1109/ICITEED.2013.6676243.
- Sun, C. T., Chen, L. X. and Chu, H. M. (2018) 'Associations among scaffold presentation, reward mechanisms and problem-solving behaviors in game play', *Computers and Education*. Elsevier, 119(1001), pp. 95–111. doi: 10.1016/j.compedu.2018.01.001.

Supekar, K. *et al.* (2015) 'Remediation of childhood math anxiety and associated neural circuits through cognitive tutoring', *Journal of Neuroscience*, 35(36), pp. 12574–12583. doi: 10.1523/JNEUROSCI.0786-15.2015.

Swetz, F. J. (1993) *Learning Activities from the History of Mathematics*. Walch Publishing.

Tahir, R. and Wang, A. I. (2020) 'Codifying Game-Based Learning : Development and Application of LEAGUE Framework for Learning Games', *Electronic Journal of e-Learning*, 17(4), pp. 69–87. doi: 10.34190/JEL.18.1.006.

Takeuchi, L. M. and Vaala, S. (2014) 'Level up learning: A national survey on teaching with digital games', p. 66 p.

Tang, S., Hanneghan, M. and El-Rhalibi, A. (2007) 'Pedagogy Elements, Components and Structures for Serious Games Authoring Environments', *5th International Game Design and Technology Workshop (GDTW 2007)*, pp. 26–34.

Tang, S., Hanneghan, M. and Rhalibi, A. El (2009) 'Introduction to Games-Based Learning', in Connolly, T., Stansfield, M., and Boyle, L. (eds) *Games Based Learning Advancements for MultiSensory Human Computer Interfaces Techniques and Effective Practices*. Hershey: IGI Global, pp. 1–18.

The Lydian Hill Foundation and The Geena Davis Institute on Gender in Media (2018) 'Portray her: Representations of women STEM characters in media', pp. 1–29.

Tobias, S., Fletcher, J. D. and Wind, A. P. (2014) 'Game-Based Learning', in J. Michael Spector, M. David Merrill, Jan Elen, M. J. B. (ed.) *Handbook of Research on Educational Communications and Technology: Fourth Edition*. 4th edn. Denton, TX: Springer Science & Business Media, pp. 347–248. doi: 10.1007/978-1-4614-3185-5.

- Tokac, U., Novak, E. and Thompson, C. G. (2019) 'Effects of game-based learning on students' mathematics achievement: A meta-analysis', *Journal of Computer Assisted Learning*, 35(3), pp. 407–420. doi: 10.1111/jcal.12347.
- Torrente, J. *et al.* (2010) '<e-Adventure>: Introducing Educational Games in the Learning Process', *Proceedings of the 2010 IEEE Global Engineering Education Conference (EDUCON 2010)*, pp. 1121–1126. doi: 10.1109/EDUCON.2010.5493056.
- Tsarava, K. *et al.* (2017) 'Training computational thinking: Game-based unplugged and plugged-in activities in primary school', *Proceedings of the 11th European Conference on Games Based Learning, ECGBL 2017*, (October), pp. 687–695.
- Tüzün, H. *et al.* (2008) 'Evaluation of Computer Games for Learning About Mathematical Functions', *Journal of Educational Technology*, 5(2), p. 9.
- Tüzün, H. *et al.* (2009) 'The effects of computer games on primary school students' achievement and motivation in geography learning', *Computers and Education*, 52(1), pp. 68–77. doi: 10.1016/j.compedu.2008.06.008.
- Vanbecelaere, S. *et al.* (2020) 'The effects of two digital educational games on cognitive and non-cognitive math and reading outcomes', *Computers and Education*. Elsevier, 143(April 2019), p. 103680. doi: 10.1016/j.compedu.2019.103680.
- Vankúš, P. (2008) 'Games Based Learning in Teaching of Mathematics At Lower Secondary School', *Acta Didactica Universitatis Comenianae Mathematics*, 8(8), pp. 1–19.
- Verkijika, S. F. and De Wet, L. (2015) 'Using a brain-computer interface (BCI) in reducing math anxiety: Evidence from South Africa', *Computers and Education*. Elsevier Ltd, 81, pp. 113–122. doi: 10.1016/j.compedu.2014.10.002.

Vianna, E. and Stetsenko, A. (2006) 'Embracing History through Transforming It: Contrasting Piagetian versus Vygotskian (Activity) Theories of Learning and Development to Expand Constructivism within a Dialectical View of History', *Theory & Psychology*, 16(1), pp. 81–108. doi: 10.1177/0959354306060108.

Vukovic, R. K., Roberts, S. O. and Green Wright, L. (2013) 'From Parental Involvement to Children's Mathematical Performance: The Role of Mathematics Anxiety', *Early Education and Development*, 24(4), pp. 446–467. doi: 10.1080/10409289.2012.693430.

Waite, S. and Pratt, N. (2011) 'Theoretical perspectives on learning outside the classroom: relationships between learning and place', in *Children Learning Outside the Classroom: From Birth to Eleven*. SAGE, pp. 7–21.

Wang, Z. *et al.* (2014) 'Who is afraid of math? Two sources of genetic variance for mathematical anxiety', *Journal of Child Psychology and Psychiatry and Allied Disciplines*, 55(9), pp. 1056–1064. doi: 10.1111/jcpp.12224.

Wastiau, P., Kearney, C. and Van den Berghe, W. (2009) *How are digital games used in schools?* Brusel: European Schoolnet.

Watson, S. *et al.* (2007) 'FearNot! An Anti-Bullying Intervention: Evaluation of an Interactive Virtual FearNot! An Anti-Bullying Intervention: Evaluation of an Interactive Virtual Learning Environment', (May 2014).

Watson, W. R., Yang, S. and Ruggiero, D. (2016) 'Games in Schools: Teachers' Perceptions of Barriers to Game-based Learning', *Journal of Interactive Learning Research*, 1, p. 229.

Watson, W. and Yang, S. (2016) 'Games in schools: Teachers' perceptions of barriers to game-based learning', *Journal of Interactive Learning Research*, 27(2), pp. 153–170.

- Wedegé, T. (1999) 'To know or not to know - Mathematics, that is a question of context', *Educational Studies in Mathematics*, 39(1–3), pp. 205–227. doi: 10.1023/A:1003871930181.
- Whitton, N. (2009) *Learning with Digital Games, Learning with Digital Games*. doi: 10.4324/9780203872987.
- Wijers, M., Jonker, V. and Drijvers, P. (2010) 'MobileMath: Exploring mathematics outside the classroom', *ZDM - International Journal on Mathematics Education*, 42(7), pp. 789–799. doi: 10.1007/s11858-010-0276-3.
- Wu, W. H. *et al.* (2012) 'Investigating the learning-theory foundations of game-based learning: A meta-analysis', *Journal of Computer Assisted Learning*, 28(3), pp. 265–279. doi: 10.1111/j.1365-2729.2011.00437.x.
- Yeh, Y.-T., Hung, H.-T. and Hsu, Y.-J. (2017) 'Digital Game-Based Learning for Improving Students' Academic Achievement, Learning Motivation, and Willingness to Communicate in an English Course', *2017 6th IIAI International Congress on Advanced Applied Informatics (IIAI-AAI)*, pp. 560–563. doi: 10.1109/IIAI-AAI.2017.40.
- Yi, H. L. (2011) 'Designing serious games to enhance political efficacy and critical thinking disposition for college students: The case of Taiwan', *Proceedings - 2011 3rd International Conference on Games and Virtual Worlds for Serious Applications, VS-Games 2011*, pp. 148–151. doi: 10.1109/VS-GAMES.2011.29.
- Yin, H. *et al.* (2015) 'A data-driven approach for online adaptation of game difficulty', in *2015 IEEE Conference on Computational Intelligence and Games*, pp. 146–153. doi: 10.1109/CIG.2015.7317918.

Young, M. F. *et al.* (2012) 'Our Princess Is in Another Castle: A Review of Trends in Serious Gaming for Education', *Review of Educational Research*, 82(1), pp. 61–89. doi: 10.3102/0034654312436980.

Zhang, L. and Shang, J. (2017) 'Understanding the Educational Values of Video Games from the Perspective of Situated Learning Theory and Game Theory', in *Proceedings - 5th International Conference on Educational Innovation through Technology, EITT 2016*, pp. 76–80. doi: 10.1109/EITT.2016.22.

Zuiker, S. J. and Anderson, K. T. (2019) 'Fostering Peer Dialogic Engagement in Science Classrooms with an Educational Videogame', *Research in Science Education*. Research in Science Education. doi: 10.1007/s11165-019-9842-z.

Appendices

Appendix 1 - Preliminary multidimensional self-reporting survey on game-based learning

English version

You are invited to participate in this survey, which aims to gather teachers' perceptions about the use of digital and non-digital games as a teaching and learning tool. This study is being conducted by Mariana Rocha, PhD student at Dublin Institute of Technology, and this questionnaire asks about your personal beliefs of digital and non-digital games as an educational tool. If you have any questions or queries, please do not hesitate to contact me: mariana.rocha@mydit.ie

Your participation in this research is completely voluntary, and there are no risks associated with this project. However, in case you feel uncomfortable answering any questions, you can withdraw from the survey at any point. All information submitted as part of this study will be used only for this PhD research project. At no point will any individual respondent be identified by name.

-
- | | |
|--|---|
| 1. In what country is your school located? | 5. What is your age group? |
| | <input type="checkbox"/> 20-25 <input type="checkbox"/> 26 - 30 |
| 2. In what city (nearest city or town) is your school located? | <input type="checkbox"/> 31 – 35 <input type="checkbox"/> 36 – 40 |
| | <input type="checkbox"/> 41 – 45 <input type="checkbox"/> 46 - 50 |
| 3. Is it a public or private school? | <input type="checkbox"/> 51 – 55 <input type="checkbox"/> 55+ |
| <input type="checkbox"/> Public School | 6. What is your gender? |
| <input type="checkbox"/> Private School | <input type="checkbox"/> Female |
| <input type="checkbox"/> Prefer not to answer | <input type="checkbox"/> Male |
| 4. To which year group you teach? | <input type="checkbox"/> Prefer not to answer |

7. According to the descriptions, please, determine your degree of familiarity with computer technologies.

- Unfamiliar - I don't have experience with computer technologies.
- Newcomer - I have attempted to use computer technologies, but I still require help on a regular basis.
- Beginner - I perform basic functions in a limited number of computer applications.
- Average - I have a general competency in a number of computer applications.
- Advanced - I have the ability to competently use a broad spectrum of computer technologies
- Expert - I am extremely proficient in using a wide variety of computer technologies.

8. Do you use games as an educational tool in the classroom or recommend students to play games at home?

- Yes No

9. If you don't use any games, please, explain why and go to question 17:

10. Which type of games do you use in the classroom or recommend your students to play at home?

- Digital games
- Non-digital games
- Both

11. Which type of games do you recommend your students to play at home?

- Digital games
- Non-digital games
- Both

12. How often do you use digital games in the classroom?

- Never Rarely Monthly
- Less than once a week Once a week
- More than once a week

13. How often do you use non-digital games in the classroom?

- Never Rarely Monthly
- Less than once a week Once a week
- More than once a week

14. Which digital games do you use in your classroom?

15. Which non-digital games do you use in your classroom?

16. Why do you use games in your classroom?

- To cover content mandated by national/local curriculum
- To teach supplemental content
- To assess students learning
- For students practice the content learned
- Other:

17. Please, mark how much you agree with each of the following statements:

a. Games help students to achieve learning goals

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

b. Games improve students' motivation and engagement in learning

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

c. Games make it easier to understand how concepts can be applied in daily life

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

d. Games improve the interaction between students

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

e. There is sufficient time to involve games in classroom lessons/routine

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

f. Low costs are involved in using games as a teaching tool

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

g. Games cover the curriculum content

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

h. Games are an easy way of assessing my students learning

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

i. Games design is often too simple, and they lack proper pedagogical design

- Strongly agree Agree
- Neutral Disagree
- Strongly disagree

Portuguese version

1. Em qual país se localiza sua escola?
2. Em qual cidade se localiza sua escola?
3. A escola em que você trabalha é pública ou particular?
 - Escola pública
 - Escola privada
 - Prefiro não responder
4. Em quais níveis escolares você leciona?
5. Qual é a sua faixa etária?
 - 20-25 26 - 30
 - 31 - 35 36 - 40
 - 41 - 45 46 - 50
 - 51 - 55 55+
6. Qual é o seu gênero?
 - Feminino
 - Masculino
 - Prefiro não responder
7. Como você classificaria a sua familiaridade com a tecnologia digital (computadores, tablets etc.)?
 - Não familiarizado - Não tenho experiência com tecnologias de informática.
 - Pouco familiarizado - tentei usar tecnologias de computador, mas ainda preciso de ajuda regularmente.
 - Iniciante - eu executo funções básicas em um número limitado de aplicativos de computador.
 - Médio - tenho competência geral em vários aplicativos de computador.
 - Avançado - tenho a capacidade de usar com competência um amplo espectro de tecnologias de computador
 - Especialista - Sou extremamente proficiente no uso de uma ampla variedade de tecnologias de computador.
8. Você adota jogos como ferramentas educacionais em sala de aula ou recomenda alunos a jogarem em casa?
 - Sim Não
9. Se você não adota nenhum jogo, por favor, explique o motivo e siga para a questão 17:
10. Qual tipo de jogo você adota em sala de aula ou recomenda que seus alunos joguem em casa?
 - Jogos digitais
 - Jogos não digitais
 - Ambos
11. Qual tipo de jogo você recomenda que seus alunos joguem em casa?
 - Jogos digitais
 - Jogos não digitais
 - Ambos
12. Com que frequência você usa jogos digitais em sala de aula?
 - Nunca Raramente Uma vez por mês
 - Menos de uma vez por semana
 - Uma vez por semana Mais de uma vez por semana
13. Com que frequência você usa jogos não-digitais em sala de aula?
 - Nunca Raramente Uma vez por mês
 - Menos de uma vez por semana
 - Uma vez por semana Mais de uma vez por semana
14. Qual jogo digital você utiliza em sala de aula?
15. Qual jogo não-digital você utiliza em sala de aula?
16. Por que você usa jogos em sala de aula?
 - Para cobrir o conteúdo do currículo oficial
 - Para ensinar conteúdo extra-curricular
 - Para avaliar a aprendizagem dos alunos

Para que os alunos possam praticar o conteúdo ensinado

Outro:

17. Por favor, selecione o quanto você concorda com as frases abaixo:

a. Os jogos ajudam o aluno a aprender

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

b. Os jogos aumentam a motivação e o engajamento dos estudantes no processo de aprendizagem

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

c. Os jogos facilitam a compreensão de como conceitos aprendidos na escola podem ser aplicados no cotidiano do aluno

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

d. Os jogos aumentam a interação entre os alunos

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

e. O tempo de aula é suficiente para incluir jogos na rotina escolar

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

f. Os custos envolvidos no uso de jogos como ferramenta de ensino são baixos

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

g. Os jogos podem ser usados para cobrir o ensino do conteúdo presente no currículo escolar

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

h. Os jogos são ferramentas úteis para avaliar se meus alunos estão aprendendo

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

i. Geralmente, os jogos são muito simples e não contam com um desenho pedagógico apropriado para que sejam utilizados como ferramenta de ensino

Concordo totalmente

Concordo Não concordo nem discordo

Discordo Discordo totalmente

Spanish version

1. ¿Cuál es el país de la escuela en la que trabaja?

2. ¿Cuál es la ciudad de la escuela en la que trabaja?

3. ¿Es una escuela pública o privada?

- Escuela pública
- Escuela privada
- Prefiero no contestar

4. ¿Cuál es el tema y cuál es el nivel de la escuela que enseña?

5. ¿Cuál es su edad?

- 20-25 26 - 30
- 31 – 35 36 – 40
- 41 – 45 46 - 50
- 51 – 55 55+

6. ¿Cuál es su género?

- Femenino
- Masculino
- Prefiero no contestar

7. ¿Cómo calificaría su familiaridad con la tecnología digital (ordenadores, tabletas, etc.)?

- Insuficiente
- Suficiente.

Buena.

Avanzada.

Expert.

8. Utiliza juegos como una herramienta educativa en el aula?

Sí No

9. Por favor, explique por qué no utiliza juegos como una herramienta educativa:

10. ¿Qué tipo de juegos utiliza en el aula?

- Juegos digitales
- Juegos no digitales
- Ambos

11. ¿Qué tipo de juego recomienda a sus alumnos a jugar en casa?

- Juegos digitales
- Juegos no digitales
- Ambos

12. ¿Con qué frecuencia utiliza juegos digitales en su clase?

- Nunca Raramente Mensual
- Menos de una vez a la semana Una vez a la semana Más de una vez a la semana

13. ¿Con qué frecuencia utiliza juegos no digitales en su clase?

Nunca Raramente Mensual
 Menos de una vez a la semana Una vez a la semana Más de una vez a la semana

14. ¿Qué juegos digitales utiliza en el aula?

15. ¿Qué juegos no digitales utiliza en el aula?

16. ¿Por qué usan los juegos en su clase?

Para cubrir el contenido estipulado por las normas establecidas (nacionales o locales)

Para enseñar contenido extracurricular

Para evaluar el aprendizaje de los estudiantes

Para los estudiantes practicar el contenido aprendido

Otro:

17. Por favor, seleccione su grado de acuerdo con cada una de las siguientes afirmaciones:

a. Los juegos ayudan a los estudiantes a alcanzar las metas de aprendizaje

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

b. Juegos estimulan la motivación y la participación de los estudiantes en el proceso de aprendizaje

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

c. Juegos hacen más fácil entender cómo los conceptos se pueden aplicar en la vida diaria

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

d. Juegos aumentan la interacción entre los alumnos

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

e. Hay tiempo suficiente para el uso de juegos en la rutina del aula

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

f. Los costos involucrados en el uso de juegos como herramienta de enseñanza son bajos

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

g. Los juegos pueden cubrir el contenido de los programas

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

h. Los juegos son una forma sencilla de evaluar lo que mis estudiantes aprendan

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

i. Los juegos son por lo general muy simple y no tiene un diseño pedagógico adecuado

Totalmente de acuerdo De acuerdo Neutral Discrepar Muy en desacuerdo

Italian version

1. In che scuola/instituto lavori attualmente?

2. In quale provincia si trova la tua scuola/instituto?

3. Indica se l'instituto per cui lavori e' pubblico o privato

Scuola Privata

Scuola Pubblica

Preferisco non rispondere

4. In che classe (o classi) insegni?

5. Indica la tua fascia di eta':

20-25 26 - 30

31 - 35 36 - 40

41 - 45 46 - 50

51 - 55 55+

6. Sesso

Femminile

Maschile

7. Come giudichi la tua familiarita' con la tecnologia digitale (computers, tablets, ...)

Pessima

Sufficiente

Buona

Avanzata / Ottima

8. Utilizzi giochi in classe come strumento educativo?

Si No

9. Quali sono i motivi per cui non utilizzi giochi digitali in classe?

10. Che tipo di gioco utilizzi in classe?

Giochi digitali

Giochi non-digitali

Entrambi

11. Che tipo di giochi educativi suggerisci ai tuoi studenti di usare a casa?

Giochi digitali

Giochi non-digitali

Entrambi

12. Con che frequenza utilizzi giochi digitali in classe?

Mai Raramente Una volta al mese

Piu' di una volta la mese (ma meno di una volta a settimana) Una volta alla settimana Più di una volta a settimana

13. Con che frequenza utilizzi giochi NON digitali in classe?

Mai Raramente Una volta al mese

Piu' di una volta la mese (ma meno di una volta a settimana) Una volta alla settimana Più di una volta a settimana

14. Quali giochi digitali utilizzi in classe? (se possibile, elenca i nomi dei giochi usati)

15. Quali giochi NON digitali utilizzi in classe? (se possibile, elenca i nomi dei giochi usati)

16. Perche' utilizzi giochi in classe?

Per presentare/insegnare materiale didattico obbligatorio/incluso nel curriculum nazionale

Per presentare/insegnare materiale supplementare

Per valutare l'apprendimento degli studenti

Per facilitare la pratica del materiale didattico da parte degli studenti

Altro:

17. Indicare quanto sei d'accordo con ciascuna delle seguenti affermazioni:

a. I giochi aiutano gli studenti ad apprendere

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

b. I giochi aumentano la motivazione e il coinvolgimento degli studenti nell'apprendimento

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

c. I giochi rendono piu' facile comprendere come mettere in pratica i concetti insegnati.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

d. I giochi migliorano l'interazione tra gli studenti.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

e. C'e' tempo a sufficienza per utilizzare giochi in classe.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

f. I costi associati all'utilizzo di giochi in classe sono bassi.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

g. I giochi possono essere utilizzati per insegnare il curriculum scolastico.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

h. I giochi sono uno strumento facile da usare per verificare il grado di apprendimento dei miei studenti.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

i. I giochi sono spesso troppo semplici e progettati tenendo in scarsa considerazione teorie pedagogiche.

Si, totalmente d'accordo Si, sono d'accordo Neutrale No, non sono d'accordo No, fortemente in disaccordo

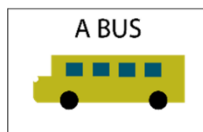
Appendix 2 - Group interview questions

- 1) Tell me what you like the most on the game.
- 2) Tell me something you didn't like in the game.
- 3) Who was your favourite character?
- 4) Which game was the hardest one? Why?
- 5) How did you feel when you were playing?
- 6) Did you like to help other players? Why?
- 7) How did you feel when you couldn't solve a challenge in the game?
- 8) What would you change in the game?
- 9) Is this a game that you would play only in school, or would you play it in your own free time?
- 10) Do you have any comments about the game?

Appendix 3 - Learning Outcomes in Mathematics for Children

The following questions were part of the survey used to measure students' mathematics performance before and after playing Once Upon a Maths.

Question 1: If you had to measure the objects below using parts of your body, which one would you use? Connect them.



Question 2: Knowing that:

$$\text{Red Circle} = 20$$

$$\text{Green Triangle} = 8$$






$$\text{Blue Square} = 10$$

How much is $\text{Red Circle} + \text{Green Triangle} + \text{Blue Square} ?$

Question 3: Draw a star in the square C3:

| | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |

Question 4: Put the pictures in order to tell the steps for brushing your teeth. Write 1, 2, 3, 4 or 5 in the boxes.

| | | | | |
|---|---|--|--|--|
| <p>rinse toothbrush</p>  | <p>spit in sink</p>  | <p>toothpaste on brush</p>  | <p>wet toothbrush</p>  | <p>brush teeth</p>  |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> | <input type="text"/> |






Appendix 4 - Abbreviated Mathematics Anxiety Scale (mAMAS)

The following survey was adopted to measure the students' levels of mathematics anxiety before and after playing Once Upon a Maths.

Instructions:

Please give each sentence a score in terms of how you would feel during each situation.

Use the scale at the right side and circle the number which you think best describes how you feel.

| |  |  |  |  |  |
|---|---|---|---|---|---|
| 1. Having to complete a worksheet by yourself. | 1 | 2 | 3 | 4 | 5 |
| 2. Thinking about a maths test the day before you take it. | 1 | 2 | 3 | 4 | 5 |
| 3. Watching the teacher work out a maths problem on the board. | 1 | 2 | 3 | 4 | 5 |
| 4. Taking a maths test. | 1 | 2 | 3 | 4 | 5 |
| 5. Being given maths homework with lots of difficult questions that you have to hand in the next day. | 1 | 2 | 3 | 4 | 5 |
| 6. Listening to the teacher talk for a long time in maths. | 1 | 2 | 3 | 4 | 5 |
| 7. Listening to another child in your class explain a maths problem. | 1 | 2 | 3 | 4 | 5 |
| 8. Finding out you are going to have a surprise maths quiz when you start your maths lesson. | 1 | 2 | 3 | 4 | 5 |
| 9. Starting a new topic in maths. | 1 | 2 | 3 | 4 | 5 |

Appendix 5 - Schools' recruitment letter

Happy Maths Project: How Educational Games can impact learners' performance and reduce Maths anxiety. Pilot Study Invitation

Happy Maths is a project that aims to develop the next generation of Educational Games for Maths and study their impact on students' performance and Maths anxiety levels.

The project is the result of 3-year collaborative research into game-based learning for STEM between TU-Dublin, Trinity College Dublin, SFI ADAPT centre and Bridge21. We have developed two educational games: *Maths Duel*, a digital card game focused on problem-solving and strategic thinking, and *Once Upon a Maths*, a graphic adventure mixing Maths and History. The games target pupils aged 7 to 13.

We believe games could be a tool to improve students' Maths performance in an engaging and more relaxed way. They can provide an alternative form of practising, and assessing Maths learning outcomes, replacing paper-based exercises and tests. Games can reduce Maths anxiety, the single biggest reason for poor Maths performance, affecting 2 million students in the UK only.

Our games are adaptable to the pupil's pace and characteristics; they can be personalized and provide learning analytics for the teachers to monitor the progress of their class. They focus on problem-solving, strategic thinking and situated learning, where students learn Maths in a real context.

The Happy maths project consists of different activities for both *formal* and *informal* education. Regarding formal education, we are looking for primary schools in Ireland who are willing to partner up in order to run a pilot study.

The pilot study aims to deploy and evaluate the impact of our games on formal education, including teachers' practice, students' performance and Maths anxiety levels. The study will

be run by a member of our team. It will consist of workshop sessions with teachers, in-class sessions with our team members over the year, and feedback session. We will provide the required IT infrastructure (tablets and connectivity). Ideally, our pilot study requires a two-hour monthly commitment from January to June, but teachers can decide as regards their own contribution. Interested teachers are free to use our games as much as they like, or recede from the pilot study at any time. Data collected in the context of the project will be completely anonymized and used only for the aim of the pilot study.

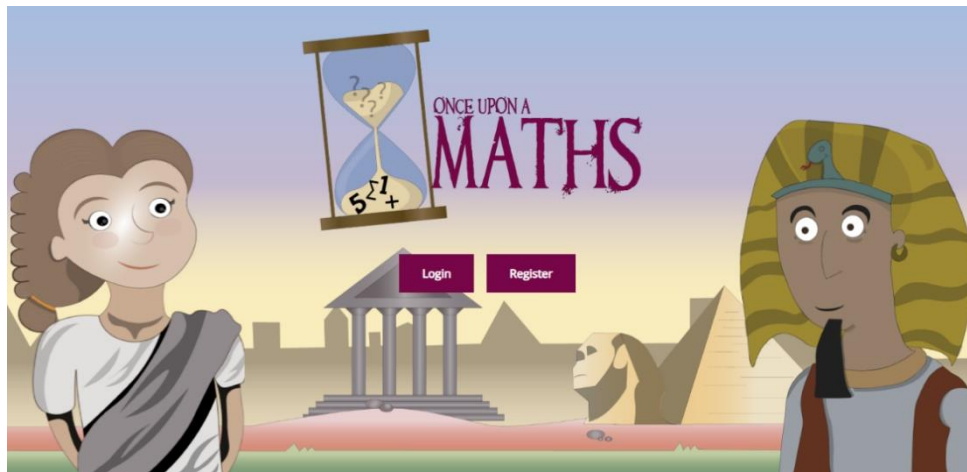
We would be grateful if you could sign our letter of support expressing your interest to take part in the pilot study.

Thank you for your time.

Dr. Pierpaolo Dondio and Mariana Rocha

For more info, you can write to pierpaolo.dondio@dit.ie

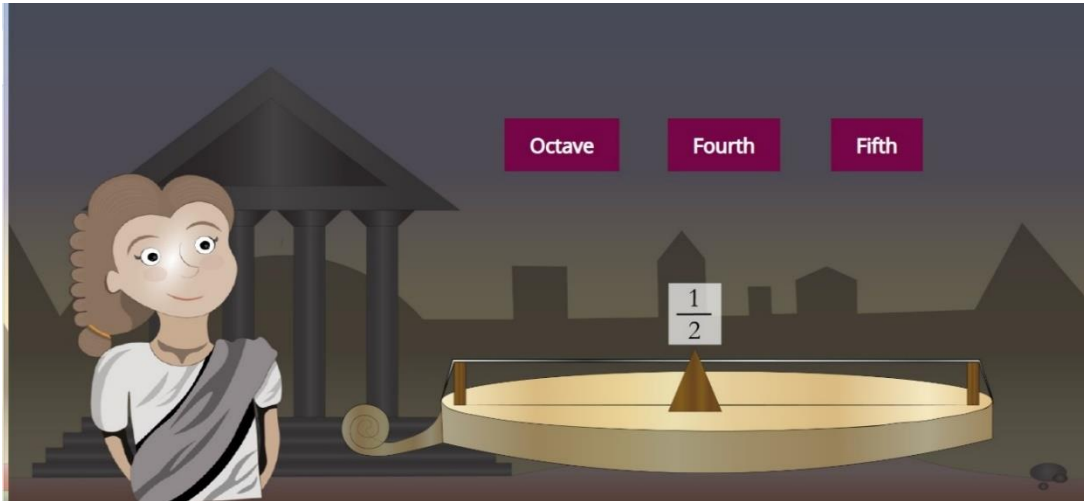
Once Upon a Maths is an exciting adventure videogame with a narrative based in the History of Mathematics. During the game, the player interacts with characters that participated in the development of Mathematics and are challenged to use this knowledge to solve real-life problems. This learning process helps to give meaning to Mathematics and leads the player to reflect on the importance and beauty of Maths!



Players travel through ages and meet famous scientists, interesting characters and learn Maths on the way.



Help Nebamun, a sculptor from Ancient Egypt to measure and sort out his vases



Hypatia, the Greek scientist, will teach you how fractions are music. Maths sounds good!

To whom it may concern

As the principal of _____, I am happy to support the Happy Maths project. Specifically, our school will be happy to be part of the pilot study described in the project, which involves testing and evaluating the Educational games described in the proposal in our classes. For further questions concerning this letter, as well as the coordination of the Happy Maths initiative, please contact Dr. Pierpaolo Dondio (pierpaolo.dondio@dit.ie).

Yours sincerely,

Printed Name: _____

Date: _____

Appendix 6 – Parent/Guardian's letter of consent

Dear parent,

We are inviting your child to participate in a research study realized in your child's school. This form has important information about this study. Please, read it carefully and, in case you agree with your child's participation, sign it at the end.

Thank you for your time!

Why are you doing this study?

Happy Maths is a project that aims to develop the next generation of Maths games and study their impact on learning performance and engagement. We are inviting your child to participate in a research study that evaluates the impact of our games on formal education. The study will be run by a member of our team, together with your child's teacher. The aim is to collect children's perceptions about those games, identifying what they think about the usability, design and game content, and analyzing if these tools improved their knowledge of Mathematics concepts.

What will my child be asked to do?

First, we will ask your child to answer a validated questionnaire about how they feel about Maths. The questionnaire was designed for children and consists of only nine questions to be answered with an emoticon face (a copy of the questionnaire is on the next page). Then, your child will play one of our educational games. The duration of the study is 6 weeks. After playing the game, your child is invited to participate in a group chat with other students, where we will ask their opinions about the game. Your child will be in a safe environment and only have to say something in case s/he wants to.

Besides, the school will share with us the age and gender of your child, and his/her results of Maths tests. However, we will not have access to the name of your child – to protect students' privacy, data will be identified by random ids. Your child will also receive a document similar to this one where s/he will tell us if agree in participating in this study.

Can I do something to help?

Yes, you can! If you wish, the parents/guardians or siblings of your child can participate in the study by answering the Maths anxiety questionnaire at the end of this document. The result of this is also anonymous, and the aim is to study the link between family and child perceptions about mathematics.

What are the possible risks or discomforts to my child?

To the best of our knowledge, the things your child would be doing in this study have no more risk of harm than the risks of everyday life.

What are the possible benefits for my child or others?

This study is designed to learn more about educational Maths games. Playing our games can increase your child's Mathematics performance and change his/her attitude towards this subject. Your child will also gain access to our games at home with no costs. The study results can also help other children in the future.

How will you protect the information you collect about my child?

Results of this study may be used in publications and presentations, but your child will never be identified. The researchers will keep the results of this study (such written observations and survey results) in a password-protected database, and they will only be used by the researchers for study purposes.

Financial Information

Participation in this study will involve no cost to you or your child. Your child will not be paid for participating in this study.

What are my child's rights as a research participant?

Participation in this study is voluntary. Your child may withdraw from this study at any time – you and your child will not be penalized in any way or lose any sort of benefits for deciding to stop participation. If you and your child decide not to be in this study, this will not affect the relationship you and your child have with your child's school in any way.

Who can I contact if I have questions or concerns about this research study?

If you or your child have any questions, you may contact the researchers at the following contact details:

PhD researcher: Mariana Rocha: mariana.rocha@tudublin.ie / +353 08383 59047

Lecturer: Dr Pierpaolo Dondio: pierpaolo.dondio@tudublin.ie / +353 1 402 4822

Parental Permission for Child's Participation in Research

I have read this form and understood this research study. If I have additional questions, I have been told whom to contact. I give permission for my child to participate in the research study described above and will receive a copy of this Parental Permission form after I sign it.

Parent / Guardian signature: _____

Parent / Guardian printed name: _____

Your child's printed name: _____

Date _____

Appendix 7 - Transcription of group interviews

Classroom 1 (1st class)

M: So, now, I would like to have a chat because I want to hear your opinion about the game. Ok? So I have a few questions for you and you can be very honest, don't worry, you won't hurt my feelings, you can tell the truth. Is that alright?

C: Yes.

M: Ok. So the first question is what you like the most in Once Upon a Maths, the game we were playing.

C: I like the... When we were trying to train the dragon?

M: Oh, ok, the last game. That's the one you like the most, very good. What about you?

C: The music one.

M: The music one? The Ancient Greece. Very nice. You?

C: The one where you measure the pot.

M: Oh, the first one, where you measure things? And you?

C: My favourite thing about the game is probably, it is very good for young children to play because it might teach them a little bit more about Maths. And also is very entertaining.

M: Nice, thank you. You?

C: I like the one with the dragon.

M: The one with the dragon? Yes, the last one.

C: I like the one with the maze.

M: The maze? Nice, yes, the one where you had to carry the vase. And you?

C: The one where you teach the dragon and the music one.

M: Did you all choose the dragon?

[some kids scream "yes", some scream "no"]

M: Ok. I'm gonna ask you about that later as well. Anybody else wants to talk?

C: I liked to weigh stuff.

C: I like the dragon.

C: I like the one where you weigh stuff.

C: I liked Ancient Egypt.

M: All of it?

C: Yeah.

M: Very good. And you?

C: I liked... When you measure stuff and when you weigh.

M: And you?

C: I liked the piano.

M: Ok. You?

C: I liked when you play with the music one.

M: Nice. The second one. And you?

C: I like the dragon.

C: I like the...

[a message from the principle start to play on the radio]

[kids start to talk with the teacher about that]

M: Ok. And you?

C: I liked everything.

C: It was really good and it messes with your brain.

M: Which one you are talking about?

C: All of them!

M: All of them! Good. And you?

C: All of them.

M: And you so we can move to the next question?

C: All of them!

M: That's very nice. Now, something you didn't like. Be honest, you can tell what you didn't like. You?

C: Nothing.

M: Nothing? That can't be true!

C: I didn't like the first one because it was kind of too easy.

M: Oh, yeah, the Ancient Egypt one.

C: I didn't like.. The unicorn. Oh, the dragon.

M: But you didn't like the game or the character?

C: I didn't like the piano one.

C: I didn't like the last as much as I liked the first two.

M: Why?

C: It was a little bit hard.

M: Hard.

C: I didn't like the last one of training the dragon.

M: Why?

C: Because it was really hard.

M: Yeah.

C: I didn't like the last one. It was really hard and I couldn't do it.

Another child: But we worked together on that one and you did it!

M: It is ok to work together because then you get the stickers.

C: I didn't like the one where you have to get all the bars in the right size order.

M: The one where you have to weigh the animals?

C: No, the second one...

M: In the Ancient Greece? Oh, ok. Why?

C: So confusing!

M: Good to know.

C: I didn't like to answer the sheets.

M: I don't like it as well. But I am developing this game as part as my research and what I want to know is if the game is going to help you to learn more and if it's going to make you enjoy Maths more. Maybe you all love Maths but will love even more after the game, that's why I do these tests. I know it's boring but you help me a lot when you answer that, ok?

C: I don't like Maths.

M: Why?

C: Because it's boring.

M: But do you like to play the Once Upon a Maths?

C: Yes.

M: But it has Maths...

[the child laughs]

[everybody laughs]

M: It's full of Maths.

Another child: I love Maths!

[everybody starts talking]

C: I don't like games but I like the game...

M: And who is your favourite character? So remember we had Nebamun, it was the first character. The Ancient Egyptian guy. The Pythagoras, the guy from Ancient Greece that was talking about music and everything. And then the third one was the Ada Lovelace, the girl that was talking about training the dragon and the unicorn. Which one you like the most?

C: I like Ada because she was talking a lot about unicorns. I have a book of history and I think she is in it.

M: Really? That's very nice, she is a real person, all the characters are real people, they really existed and they are part of the Maths history.

C: The third one.

C: So that means the unicorns were real?

C: I like the Ancient Egyptian guy because he was talking about weighing things.

[everybody starts to talk at the same time]

C: So the unicorns are characters?

M: Well, yes, they are characters as well.

C: So they are real?

M: Well...

[everybody starts to talk at the same time]

M: The characters that were talking to you in the videos are all real, they really existed.

C: Even the dragon??

M: Hm... I'm not sure. I have to check.

[kids get excited and loud]

C: Is there a place where you can check if they are real?

M: I am not sure. You have to ask to a scientist.

C: We can ask Elisa's dad, he is a scientist.

M: Yeah, he is a scientist, maybe he knows. Ask him next week.

C: Great!

M: Which game was the hardest one?

C: The dragon?

C: The dragon.

C: None of them. I mean, every game.

C: The dragon.

C: Modern world.

C: Kind of the start and then it was easy at the end.

C: The unicorn.

C: Unicorn.

C: The unicorn and the one where you had to weigh.

C: The unicorn.

C: The last one.

C: The last one.

C: The dragon one.

C: The dragon because I didn't know what to do.

M: So maybe if you had... Because the idea was to give some information in the video but I think it wasn't very clear, right?

C: Yeah.

C: The last one, the dragon.

C: I found the last one hard.

M: And how did you feel while playing the game? In one word, how did you feel?

C: Amazing!

C: Good.

C: Good.

C: Interested.

C: Good.

C: I feel that Maths was invading me!

C: Really fun.

C: Happy.

C: Happy too.

M: Did you like to help other players? Why?

C: I don't know.

C: I have no idea.

C: Because I like being nice

C: Because I got to figure out... If I didn't get something before I got when I could do it again.

C: Because I got more stickers.

C: Probably because... I don't really know. But when help someone, they can help more people...

C: I like being helpful.

M: That's nice. And you?

C: I liked being kind.

M: Kind, yeah. And how did you feel when you couldn't solve a challenge in the game?

C: Sad.

C: I felt like smashing the iPad.

C: I felt really angry and just wanted to delete the game.

C: I felt nervous and frustrated.

C: Bad.

M: And what would you change in the game? Something you would change.

C: The last one. Delete and put another one.

C: The last one. Make it easier.

C: More levels.

C: Give hints of how to play.

[kids talk at the same time]

Classroom 2 (1st class)

M: The first question is what you liked the most in the game we played? So I will make the question, then you raise our hand and I will choose who is going to answer. You.

C: That there were different levels and you could weigh stuff.

M: And what was your favourite game.

C: The last one.

M: The last one? The modern world. Good. And you?

C: I liked the middle one.

M: The Ancient Greece? Why?

C: I kind of forgot. But it's because you had to do the music.

M: Oh, you like music.

C: I liked Modern World because you had to like... Raise the dragon when you finished.

M: Which animal you chose?

C: I chose unicorn first but then I changed my mind.

M: Ok. And you?

C: Ancient Greece.

M: Why?

C: Because I found that pretty easy and I play music.

C: Me too. We all play music.

C: I like the piano one. Because I like music.

C: I like Modern World. Because I like to make the unicorn fly.

C: I like the first one because I like measuring things.

C: I like Ancient Greece and Modern World. Because I can make the unicorn fly and guide the animal.

C: I like the Modern World because every time you didn't teach them well they just fell.

M: So you like because it's hard?

C: I just like when they fall.

C: I like Ancient Egypt and Modern World. I like Ancient Egypt because I like to measure and Modern World because I liked the little dragon.

C: I like the modern world because it's very hard and I like to make the unicorn fly.

M: Good. And you?

C: I like the Modern World. Because you could guide the unicorns.

M: Very nice. Now another question. What you didn't like?

C: I didn't like the middle one. Because it was hard.

C: I didn't like Ancient Egypt because I found the measuring really hard.

C: I didn't like the internet.

C: I didn't like the Ancient Greece. Because it was kind of hard.

C: The internet.

C: I didn't like when the unicorn fell.

C: Modern world. It was so hard.

C: I didn't like the internet.

C: The internet.

C: The internet!

C: When the animals fell.

C: Modern world because it was hard and I needed a lot of help, and it wasn't great because it took me a very long time.

C: I didn't like the measuring one because it was too easy.

C: I didn't like the last level because it was really hard. I picked the dragon, then I picked the unicorn, but both were hard.

M: What was the hardest game?

C: Ancient Egyptian.

C: No it wasn't

C: Modern world.

C: Modern world.

C: Modern world.

C: Ancient Greece.

C: The internet.

M: But in the game?

C: Modern world.

C: The first one.

M: How did you feel when you were playing the game?

C: Good.

C: Good.

C: Good.

C: Confident.

C: Excited.

Child: Horrified. Because I thought my dragon would die and I would have to organize a funeral which costs a lot of money.

[all children laugh]

C: Excited.

C: I felt under pressure.

M: Why?

C: Because it was a little bit hard.

M: Ok.

C: Happy.

C: Sad because they were not flying.

C: Out of this world.

M: Did you like to help your friends?

C: Yeah!

M: How did you feel when you couldn't solve a challenge in the game?

C: Horrified.

C: I felt bad because I thought I would have to stop playing the game.

C: Stressed.

C: Horrified because the unicorn died and I thought I would have to arrange a funeral and that costs a lot of money.

C: I felt so, so angry.

C: Worried because like.. I was worried like... Because I thought I wouldn't finish all the games.

C: Dumb.

C: I felt horrified.

C: I felt horrified because the game was glitching and I thought someone was hacking the iPad.

M: What would you change in the game?

C: No hacking.

C: I'd change, in Modern World, the dragon to a dog.

C: I would like if there were more levels.

C: It would be nice if there was a person to grab the unicorn and bring it back when it falls.

C: More levels.

C: I would change if the unicorn didn't learn to fly. Because I like the animals falling.

C: I would change the internet.

C: I'd change the animals.

C: I'd make it harder.

C: In Ancient Greece, when you were playing the piano, if you got it right, something different would happen at the end.

C: More levels.

Classroom 3 (2nd class)

M: So, as you may know, I developed the game, so I want to hear your opinion about it, ok? So I'm gonna ask some questions. So, do you guys play videogames at home?

[All children talk at the same time, some saying "yes", some saying "no"]

M: Is there anybody that doesn't play at all, that don't like videogames?

[One child raises the hand]

M: You don't? No problem. And what are the games you play?

[everybody talks at the same time]

M: Wait, guys, raise your hand.

Teacher: Stop, stop this minute, you know you don't scream at people like that. You put up your hands nicely.

M: Ok. So, you.

C: Minecraft.

M: And you?

C: Roblox and Minecraft.

M: Very nice. And you?

C: [couldn't understand]

C: Fifa, Minecraft, and Roblox.

C: Minecraft and SuperMario

C: [couldn't understand]

C: Fifa and [couldn't understand]

C: Roblox, [couldn't understand], and Fortnite.

C: Minecraft and Fifa.

C: MarioKart, [couldn't understand], and Roblox.

C: Minecraft.

C: Roblox, Minecraft and Fortnite.

C: Roblox, Minecraft, and Fifa.

C: Roblox.

C: Fortnite.

C: Minecraft and Fifa.

C: Minecraft.

M: Very good. Tell me what was the thing you liked the most in the game, in the Once Upon a Maths, the one we played.

C: The Modern World.

M: The Modern World. What did you like about it?

C: Uhn... Because... Uhn... Because it was hard.

M: Because it was hard. Nice. And you?

C: Modern World.

M: Yeah, why?

C: Because at first it was really, really hard, but then you could figure it out.

M: Oh, so you like the challenge?

C: Yes.

M: And you?

Teacher: Stop you two!

C: Uh... I like theeee.... The Modern World because it was a little bit hard.

M: Hum. And you?

C: I like the Modern World because you could choose who you wanted to be. [talking about the animals they could choose to train]

M: Oh, ok.

C: I liked The Modern World because I like dragons.

M: Hum.

C: The Modern World because it was very different from the other ones and there wasn't a lot of Maths on it.

M: Hum... Yeah.

C: Ancient Greece.

M: Oh, why?

C: Because I liked the instruments' sounds.

M: Oh, you liked the music on it? Nice.

C: Modern World because you could choose which animal would fly.

M: Hum. And you?

C: Modern World.

M: Modern World as well. Why?

C: Because... You can pick... Because you can pick what you...The animal that you fly.

M: Nice. You?

C: Modern World because I like unicorns.

M: And you?

C: Modern World.

M: Why?

C: Because it was really hard at the start, but the rest I could figure out.

M: And you?

C: The Ancient Egypt.

M: Why?

C: Because it's cool. I like the old times and to get the things to measure.

M: Yeah. Very good. And you?

C: Uhn... It was... The Modern World.

M: Yeah? Why?

C: Because... I like the challenge!

M: Challenge? Yeah. And you?

C: Modern World. And Ancient Greece.

M: Both? Why?

C: Because I love the music and I like how hard I had to work for Modern World, because it was so hard.

M: Very good. One last answer...

C: Modern World.

M: Why?

C: Because it's fun to fly.

M: Good. And what you didn't like? Be honest, you can say it. You raised your hand first.

C: Ancient Greece because is boring just to hear the sounds and just press the buttons.

M: You found it boring. Ok.

C: Egyptian.

M: Why?

C: Because it's just like measuring and just like moving.

M: You found it too easy or boring?

C: Boring and easy.

C: I didn't like the Ancient Egypt because you had to measure things.

M: Ok. And you?

C: I didn't like the Ancient Greece because it's really hard.

M: Ok.

C: Ancient Egypt.

M: You didn't like it? Why?

C: Because it was a bit boring.

C: The unicorn in the Modern World, that's all I didn't like about the game because I prefer dragons.

M: Ok.

C: Ancient Greece because I found it really hard and all the numbers and trying to make the music...

M: And you?

C: Ancient Egypt because it was so easy and I could bit it like in 10 seconds!

M: Good.

C: Ancient Greece because... Uhn... You really had to understand...

M: It was not clear what you had to do?

C: Well... It was really hard and I don't really like hard things...

M: Oh, ok. And you?

C: Ancient Egypt because at the end you had to weigh the animals and it was very hard and I got stuck.

M: Ok. And you?

C: Hm... Ancient Egyptian. Because it was really easy.

M: Oh, right. You?

C: Ancient Egyptian because it was really hard to measure the vases.

M: Ok.

C: Ancient Greece because I couldn't understand all the music things.

M: Ok.

C: Ancient Greece because it was really hard.

M: I think most of you said that the Ancient Greece was the hardest one?

[most of kids say "yes", a few say "no"]

M: No? What do you think?

C: I think Modern World was the hardest one.

M: It was the hardest one? But you said it was your favourite?

C: But I like because it's hard.

M: Ok. Anybody else?

C: I didn't think the Ancient Greece was hard because it tells you what order you should follow when you're tapping.

M: And which one you think is the hardest one?

C: Modern World.

M: Good. And who was your favourite character? So remember we had Nebamun, and then you had Pythagoras, and then you had Ada Lovelace. Who is your favourite?

C: Ada Lovelace.

C: Pythagoras.

C: Ada Lovelace.

C: Nebamun.

C: Ada Lovelace.

C: Nebamun.

C: Nebamun.

C: Ada Lovelace.

C: Nebamun.

C: Ada Lovelace.

C: Ada Lovelace.

C: Ada Lovelace and Nebamun.

C: Nebamun.

C: Ada Lovelace and Pythagoras.

C: All.

C: Ada Lovelace.

C: All.

C: Pythagoras.

C: Nebamun.

M: How did you feel when you were playing the game? Tell me one word, one feeling that describes it.

C: Good.

C: Happy.

C: Excited.

C: Happy and excited.

C: Happy.

C: Happy.

C: Intelligent.

C: Happy and confused.

C: Confused.

C: Bored.

C: Happy.

C: Happy.

C: Happy and confused.

C: A bit worried.

C: Worried and confused.

C: Excited.

M: Do you think you would like to play this game outside school or only when you are in school?

[all kids start to say “outside” at the same time]

M: Raise your hands how many of you would like to play only at school? Ok, four of you. The last question: did you like the videos that I showed you before the game?

All children: “Yes”

M: Did you think it helped you to understand the game?

C: Yes!

C: No!

M: How many think it helped? [starts counting]. Fourteen. Ok, the last thing: I will pick three people to make a comment about the game, anything you want to say, maybe somebody that didn't talk much. Do you want to talk? Just say something about the game. What do you think?

C: Hm... It was fun.

M: Ok. You?

C: It was really fun and made me very happy.

M: Good.

C: It was very fun and exciting and the game I like the most was the unicorn.

C: I felt excited and I was waiting to play again.

M: One last question: how many of you like Maths? [start counting]. Nineteen. Now the final question: is there something you would change in the game? I will pick two people to answer. You.

C: Ahn... A little bit easier.

M: You?

C: A little bit harder.

M: Harder...

C: You could set a difficulty setting on it.

M: Oh. That's brilliant. Guys, I have to go now, thank you so much!

[kids clap their hands]