

Using RPG-Based Learning Environment to Increase Engagement and Motivation for Learning Higher Mathematics

Evgenia Anagnostopoulou

University of Sussex, Brighton, UK

ea434@sussex.ac.uk

Abstract: Although game-based learning has been introduced in various fields, there appears to be a lack of engaging computer games that incorporate higher maths learning (Anagnostopoulou, 2021). This paper presents an exploration of how fantasy-based narrative and storytelling, through role-playing and game mechanics, can be used to increase engagement and motivation for learning higher mathematics in a role-playing game (RPG) based learning environment. As part of this research, the project developed an RPG with incorporated mathematical techniques. Players/learners access the fictional world, controlling in-game characters. Learning evolves via a storyline and six mechanics, progressively building knowledge of derivatives using puzzles with shapes, which gradually fade to the abstract notion of mathematical functions. An experiment was conducted to test the research hypothesis that an RPG based around a quest structure with concreteness fading can enable students to get a better understanding of higher mathematics in the area of differentiation without impeding their entertainment. Participants were recruited from various backgrounds and levels of mathematical knowledge and gaming experience. Data was collected through observations, interviews and two questionnaires: one to be completed before playing the game and the other after. This paper is mainly focused on the qualitative outcomes of the research. The results suggest that the method is effective, with serious learning taking place. The participants reported that they had found the game to be fun and a useful way to learn maths. Moreover, it is revealed that a PRG-based learning environment can increase engagement and motivation for learning higher maths, without invalidating entertainment. The findings have implications for the design, implementation, and evaluation of game-based learning environments for higher mathematics. The paper concludes that this approach has the potential to provide a more immersive, engaging learning experience and increase motivation for learning. Finally, recommendations on how to improve the current game as well as more bold and optimistic ideas for enhanced immersive game builds are suggested.

Keywords: Higher level maths, Game-based learning, Immersive games, Mathematics games, Interactive player experience, KS3 to KS5 maths

1. Introduction

Research demonstrates that game-based learning (GBL) is a valid and effective contemporary method that can replace traditional learning, with various advantages, such as engagement, motivation, fun, immediate feedback, causality, experiential learning, etc. (Steinkuehler, 2004; Tang et al, 2007; Wagner, 2008; Trybus, 2014; Anagnostopoulou, 2017).

This study is using digital game-based learning (DGBL) differentiating the scope into two distinct approaches. Most of educational games are built under the first approach, which uses a 'play, to learn (P2L)' style and involves games that have been designed to teach a topic; the emphasis is on learning the topic first, in a fun way as a secondary objective. In these games, the player automatically realises that the goal is to learn the educational topic included. Prensky's (2001) six structural game elements for learning are primarily related to the educational content of the game. Rules, goals and objectives, outcomes and feedback, competition and challenge refer to the learning topic, whereas interaction is limited and the storyline partial, narrow, or even non-existent.

However, the second approach, 'learn, to play (L2P)' is exactly the opposite, where fun precedes the educational process. Such games are designed to employ whichever technique is required to achieve the goals of the game; while, learning a topic, skills, or acquire general knowledge are just derivative. Mitchell and Smith (2004, p. 49) refer to this design approach, as 'Edugaming', when applied to DGBL. In these games, the educational content is intrinsically integrated into the gaming experience in a way that there is no obvious barrier between fun and learning (Fabricatore, 2000; Mitchell and Smith, 2004).

Various educational games of L2P style have been created across a range of genres. However, Anagnostopoulou (2021), exploring a wide range of the maths games available, identified a gap where there was no highly interactive game available, such as role-playing games (RPGs), with high maths level content, in the range of KS4-KS5 of the UK curriculum. To address this uncovered area, research was contacted to identify ways of intrinsically include high level maths in a game of high player experience. A role-playing game (RPG) was designed, incorporating higher maths in a way that successful learning takes place without impeding the fun aspect.

The game was tested, and the present paper is mainly focused on the qualitative findings of the research.

2. Intrinsically Incorporated Learning in a Fantasy-Based Narrative

Design-based research (DBR) is an established methodology in the field of educational games. It provides a framework for understanding the complex interactions between design, play, and learning. DBR is increasingly being used to inform the design and evaluation of educational games, as well as to build an understanding of the impact of game design on learning and motivation. In DBR, the design of educational games is based on a combination of theory, empirical data, and iterative design cycles. During the design process, designers work closely with players and educators to identify goals, develop game mechanics, design game elements, and evaluate the educational impact of their designs. Through this process, designers gain insight into how players interact with the game's educational content and how these interactions affect learning outcomes. As a result, DBR has become an important tool for understanding the complexities of educational game design (Barab and Squire, 2004).

An RPG setting was chosen as is considered ideal for educational games due to the quality of immersion it offers (Johnson et al., 2015) and well as its narrative factor, which according to Barab and Squire (2004) is a way of coherence of DBR in game systems, as it provides description and guidance for the content, and gradual unfolding of the design.

The present research design followed the six iterative phases of DBR processes as outlined by Easterday et al. (2014) "in which designers: focus the problem, understand the problem, define goals, conceive the outline of a solution, build the solution, and test the solution", but tailored to game-based learning by using elements of Room2Educ8 framework (Fotaris and Mastoras, 2022) (Figure 1).

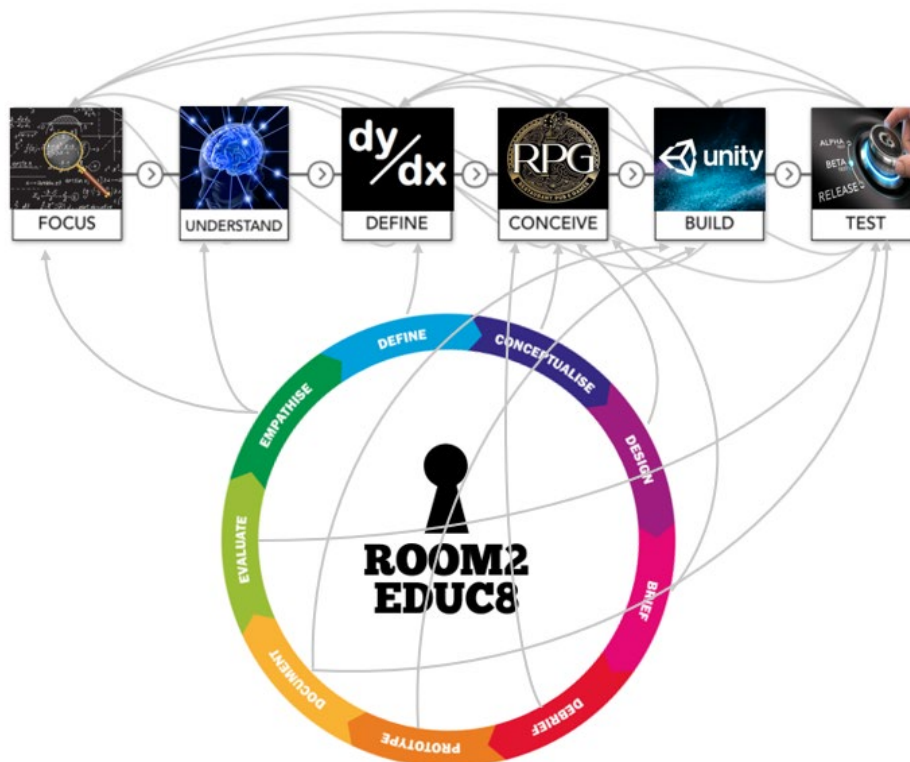


Figure 1: The six iterative phases of the design process: tailored to Room2Educ8 (adapted from Easterday et al., 2014 and Fotaris and Mastoras, 2022)

The six design phases were carried out iteratively and were applied as follows:

Focus: The game specifically targets adult learners with diverse mathematical backgrounds and varying levels of gaming experience, as well as higher education stakeholders by being designed in a way that allows for seamless integration into lessons.

Understand: A thorough literature review was conducted concerning the identified gap in mathematics games, using a diverse range of empirical methods and extensive analysis of secondary sources. Existing solutions in

DGBL within similar or related disciplines, revealing the immense appreciation learners have for immersive games.

Define: The focal point of the mathematical topic and the learning objectives centre in KS5 calculus. By the end of the learning experience, the learners are expected to demonstrate an understanding of the fundamental rules of differentiation, and effectively calculate polynomial, trigonometric and exponential derivatives, as well as use the addition law of differentiation.

Conceive: A RPG environment with a captivating fantasy setting was conceived, creating a fictional virtual world map to immerse players in an engaging experience. To ensure an optimal learning environment, various aspects were carefully considered, including virtual world modelling, narrative development, quest line design, user interface, and seamless integration of mathematical concepts into the game mechanics. The core narrative was thoughtfully organised into a series of events, allowing players to follow a linear quest structure, with a strong focus on fostering motivation through challenge, curiosity, control, and fantasy content, as described in intrinsic motivation of learning theories (Malone and Lepper, 1987). The mathematical content was incorporated into activities designed to maintain a delicate balance between challenging learners and avoiding dullness, ensuring they remained in an optimal learning zone where neither frustration nor monotony prevailed. The learning content design was based on concreteness fading theory (Fyfe et al., 2014). The mathematical concepts were intrinsically incorporated into game mechanics through a fading process of gradual chunking of information, which facilitated comprehension and learning. Derivatives started with a shape representation of the differentiation rules smoothly progressing to abstract functions, in six steps (Anagnostopoulou, 2022). Direct feedback from game mechanics enabled learners to monitor and review their progress throughout the game.

Build: For the practical implementation of the RPG prototype, Unity engine was used as the development platform. During the entire process, detailed documentation was maintained for each stage, which proved instrumental for refining areas of the project and identifying revision requirements.

Test: During the testing phase, the effectiveness of the solution is evaluated. Successive versions of the design were used iteratively. Along with testing in the development stage, Alpha and Beta pilot tests were also implemented to obtain valuable feedback regarding the design's success. The results informed the main testing, which in turn served as a means for determining whether the design has successfully attained its goals and objectives regarding the learning outcomes. Extensive documentation was also carried out throughout the entire testing phase.

2.1 Research Questions

The research questions and hypothesis concerning the qualitative analysis of the results are as follows:

Research questions

RQ1. What is the impact of a RPG-based learning environment on engagement and motivation for learning higher maths?

RQ2. How can higher level maths be included in RPGs without impeding the fun?

Research hypothesis

An RPG based around a quest structure with concreteness fading techniques will engage and motivate students to get a better understanding of higher mathematics in the area of differentiation, without impeding their fun.

3. Methodology

To test the research hypothesis an RPG with incorporated mathematical techniques, named *The Red Circle*, was designed, following the DBR process described above, and developed in Unity engine by one developer and one designer. Players can access the fictional world, controlling in-game characters to complete tasks related to the storyline. Screenshots of the game are shown in Figure 2.

An experiment was conducted with a sample of 148 participants of age range 18-60 years old. The majority of the participants were students of the University of Sussex, which was the main venue of the conducted research. The background of the participants was a mixture of low, medium, and high maths prior knowledge as well as low, medium, and high prior gaming experience.



Figure 2: Screenshots of *The Red Circle* game

The participants were asked to a) complete a pre-questionnaire, b) play the game and finally, c) complete a post-questionnaire. Concerning the qualitative part of the research, the questionnaires were designed to provide feedback regarding the participants' experience, preference of the game mechanics as well, open questions for positive and negative feedback, and resemblance of *The Red Circle* to any other game. The responses in the two questionnaires were completely anonymous, and aliases were used to match the pre to post-replies. Observations of the gameplay and interviews were also conducted to a selection of the sample to further inform of aspects that could not be identified via the questionnaires. The gameplay time was also recorded. Data was then collected and analysed.

4. Results

This paper reports on the qualitative results of the research. However, a short mention of the main quantitative outcomes is included, as the primary findings of this research pertain to the effectiveness of the game in improving mathematics learning.

4.1 Learning

The game seems to have achieved its goal of teaching the basic rules of derivatives in a fun way. In the full quantitative analysis, Anagnostopoulou (2023) reports that there was a statistically significant increase in maths scores after playing the game, particularly for the players with low prior maths knowledge.

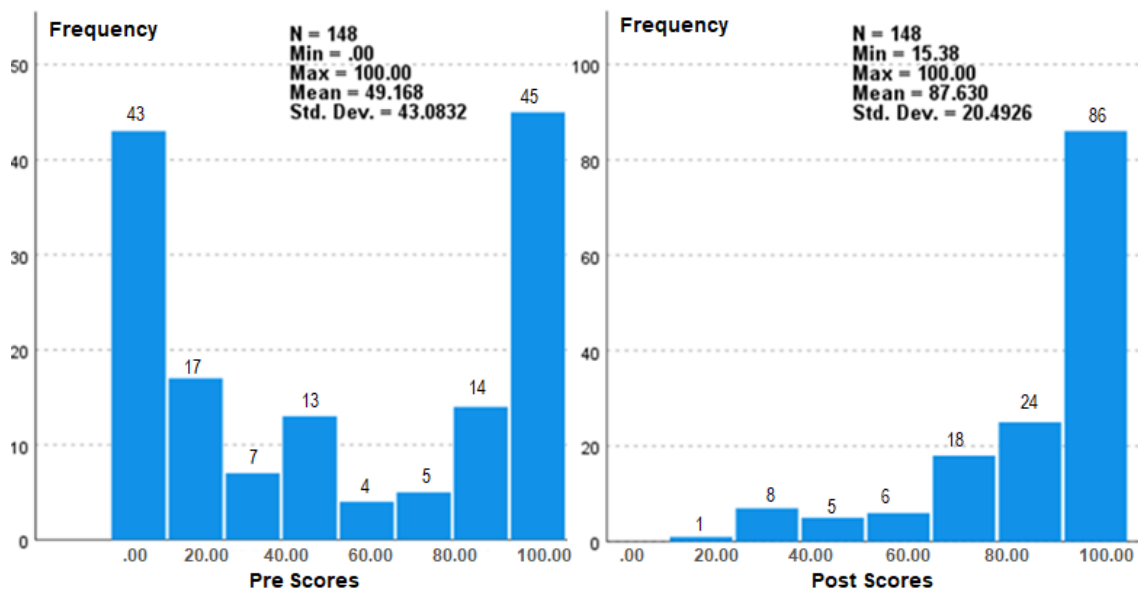


Figure 3: Pre vs. Post Scores

As seen in Figure 3, the mean value of the scores of the participants before playing the game was 49.17% with a dispersion of 43.083% which indicates that the results were highly spread out. However, after playing the game the mean was considerably increased to 87.63%, while the variability was halved. The minimum value was shifted from 0% to 15.38% corresponding to only one person from the initial 43. The mode of 100% corresponds to 86 subjects from 43 of the Pre scores. The histogram curve has been shifted towards the greater score values. This result indicates that engaging in gameplay led to a substantial enhancement of participants' mathematical knowledge. As anticipated, participants with a high mathematics background demonstrated a slight increase in their scores, affirming that the gameplay did not hinder or disrupt their existing knowledge. The group with medium prior maths knowledge experienced a notable improvement in their scores, and their feedback highlighted that the game served as an enjoyable avenue for revisiting and recalling previously acquired knowledge. However, the most intriguing result was observed among participants with low or no prior maths knowledge. The increase in their post-test scores was significant, with none of them scoring zero marks, and over half of the sample achieving full marks in the post-test.

Participants stated that the explanation of differentiation was clear and easy to follow in every step of the process, progression was well paced and the more they advanced in the game, the more they learned about the rules of derivatives. The mini games' levels were challenging enough to make progress and the gradual evolution of the puzzles allowed for better understanding of the maths concepts. Each quest had a specific goal in mind, and they could quickly learn how to complete the tasks and differentiate equations by following the hints presented. The repetitive nature of the questions consolidated knowledge and allowed to quickly recall the answers to the derivatives previously encountered in the game. Players with higher maths knowledge were surprised with the shape representation of derivatives; those that had taken maths a long time ago were happy to see that they were reminded of skills they have forgotten; and those of lower maths skills felt satisfied that they managed to learn maths in a pleasant way. Many participants recommended using such a game instead of a typical class lesson, since it is both enjoyable as well as achieves its learning goals.

4.2 Immersion and Flow

The majority of the players found the game to be immersive. They reported that the beautiful visuals, intriguing storyline, intricate world-building, and the familiarity with the memes used 'hooked' them; even the music was adding to the atmosphere of the game. Intrinsically incorporated maths in direct related to the quest and storyline was also appreciated, as it the mathematical content did not interrupt the flow. The mechanics were consistently themed between different activities and differentiation worked well as a mechanic.

4.3 Engagement and Motivation

Participants testified that overall, they had a pleasant experience playing the game. The environment was built with a comic tone, making the activity amusing. The interactions with the NPCs were entertaining due to the

dialogues having been made intuitively, with the use of relatable memes. The storyline was easy to follow, and the open world exploring was exciting. The combat was engaging, with a good level of complexity progress. The puzzles were challenging, but enjoyable once the players got the hang of them.

They also found the game motivating, particularly those with low mathematics background and low playing experience. Some stated that although they don't play games in general, they are willing to start, following their experience with *the Red Circle* game. They were interested to find out what is next on the story, and they would like to play again to explore the world more. The math puzzle aspect of the game felt a bit frustrated in the beginning for those whose maths is not their strong point, but if felt satisfying when they learnt the mechanics and could solve the puzzles. This motivated them to repeat the quests, just to prove that they can do maths. Some liked the fight feature of the game, because even if it was hard to get the mechanism, causing them to die again and again, they were excited when they were able to kill the enemies in the end. Many referred to the story and quest lines stating that they were looking forward to all the quests there are to do and asked for the follow up.

4.4 Features and Design

One of the comments stating: *"I've seen AAA games that don't flow as well as the Red Circle. For only a 2-person game build the quality is amazing."* was a particularly gratifying one, as the term 'AAA games' refers to high-budget, high-profile games in the game industry. The design and features of *the Red Circle* game were greatly appreciated by the players. They mentioned that the graphics were beautiful and captivating, the world map was well designed, and the gameplay run smoothly as intended. The majority approved the movement by clicking on the terrain as this way provides a fast-learning curve regarding navigation. The fading of UI elements when the cursor hovered over them was a nice feature, making clicking and walking easier. The storyline was described as gripping and interesting. The objectives were found to be clear, and the players could always tell exactly where they had to go and what they had to do. The game was easy to get started and there were plenty of activities with accompanying background music and sound effects. The players liked the variety of NPCs, each one of different personality along with funny dialogues. The combat feature was well built at this stage, and there was a variety of enemies to fight. The mechanics were well explained and the puzzles quite challenging; it was appreciated how they were all consistent with the game's theme.

4.5 Bugs, Challenges, and Suggestions

There was a lot of feedback on what could have been done better according to the participants perception, which although came from few participants, informs of how to improve the game. The players' comments mainly fall into the category of what is known as 'victim of own success'. The RPG design and graphics resembled a complete game like the ones released in market, developed by companies. Hence, the participants viewed it as such, expecting more of the game, without considering the limitations of this research.

Although the game runs smoothly in general terms, three main bugs were reported by the minority of the players that were found annoying, however did not impede the progress of the game.

These refer to a) a small bug that does not impede gameplay that involves a glitch on a part of the terrain which caused the motion of the player to slow down when walking over it, due of a slight textural difference in the terrain, b) a small bug where the player stuck in a building for reason that could not be identified in the given developing time; the issue was overcome by the implementation of an 'Unstuck' button, and c) a bug that was discovered during the main testing by some experienced players. The games bugged when the key 'F' was used to interact with a certain mechanics of game, instead of the normal mouse right click. It must be noted that experienced players were able to encounter this error, due to the fact that in many games 'F' is often used to interact with the world. This bug was not identified during the pilot tests, but it is easy to fix.

Navigating around in a 3D environment can be a difficult and tedious task, especially for those unfamiliar with the environment. These difficulties involve controlling the character to go around objects, sometimes passing through textures, which would lead to incorrect positions and sometimes colliding with obstacles. The path-finding system needs tweaking to better detect obstacles and plot an appropriate route for the character. Additionally, the players could not pinpoint the exact location of the character on the map as only an approximated position is shown.

Many participants found the game short and stated that they wish they had more time to play, as there was still a lot more to explore. They recommended more stories and dialogues to keep the game interesting and

engaging; use of the rest of the world map for more activities than just scenery; more practice levels; a 'Save' option, so they can resume and continue playing later.

Concerning combat mechanics, some of the experienced gamers asked for a more challenging fight with a variety of skills to use, like use of a sword and block mechanics. They did not like the fact that dying brought no consequence to the player inventory or gameplay and stated that dying is more of a nuisance than something they would want to avoid.

Some participants with high mathematical level background did not like the way that derivatives were initially explained with the use of shapes. They commented that this method of teaching derivative can be confusing to newcomers in the topic. However, no such comment of difficulty was referred by players with low mathematical background.

The players generally liked the high number of NPCs in the game, but they wish they had more dialogues instead or repeating the same meme or joke. They also requested more variety in the quests.

4.6 Timings

The total time of completion varied according to the players' maths and gaming background. The mean time of gameplay of the low age range group, which was mainly university students, was between 40-60 mins, which makes the game suitable in class during a lesson session. Longer playtime involved exploration of the map and interactions with non-player characters (NPCs).

The learning curve of the RPG's user interface, map navigation and interaction with the world was observed to be about 15-20 mins for new players and 3-5 mins for experienced players, five of which who offered to play the game again were observed to have significantly reduced their learning curve to 5-10 mins. This is expected as learning through RPGs requires more gameplay time wherein the player would repeat parts of the game and learn by trial and error, in fact transforming a simple participation to a dynamic activity incorporated to gamers' everyday lives (Herodotou, 2009).

Players with prior math knowledge were observed to be faster in the mechanics with the abstract notation of functions, while their performance in the puzzles shapes was similar to the players with no mathematical background.

4.7 Collaboration Between Players

Many players were playing in collaboration with others, on different computers but next to each other. This practice was encouraged as it marginally simulates a multiplayer environment and can give an idea of the contribution of the social aspect that this game does not address.

Collaborating players were observed to have more fun and be more immersed, discussing with each other, explaining the story, prompting each other to activities outside the quest line, such as exploring other areas of the map or even play with the assets. These players were the ones that talked to many NPCs, laughing at their memes and joke lines.

When they were encountered obstacles, such as difficulties in understanding the minigames, or lost in navigation, or use their UI, they were asking each other for help. In Sometimes they were even competing for who is going to solve the puzzles faster.

5. Conclusion

This paper presented the qualitative results of a study conducted to investigate ways of incorporating higher level mathematics in immersive digital games, without inhibiting players' fun. From the above presented results, it can be concluded that the game was successful in the teaching of differentiation in an enjoyable way. Participants' feedback indicates that an immersive RPG with a fantasy setting and storyline can increase engagement and motivation, thus enforcing the research hypothesis and questions. The mathematical content can be successfully delivered, presented in chunks of a gradual fading process. Mathematical tasks can blend in the quest structure of the storyline, taking advantage of RPG features, such as exploration, crafting, gathering items, fight enemies, etc.

5.1 Limitations

It is well-known that the development of a proper RPG game requires a great amount of investment with respect to funding, workforce as well as time (Castronova, 2007). This study is a part of a PhD thesis in

progress, therefore limited by time and resources. The game was built by only one developer and one designer. Moreover, the limited participation testing time did not allow including the original eight mechanics as set out in the initial plan.

5.2 Future Research

Apart from the immediate fixes regarding game functionality, such as the bugs identified, the short-term plans of the researcher include testing the effectiveness of learning via the game against a control group which will be taught the same topic under a normal class setting. Furthermore, the researcher intends to develop mechanics in order to fade in an eight-step process, as was originally planned. This would result in better consolidation of knowledge. The game can be further expanded to make use of the whole terrain already built for this purpose, with an extended and improved storyline to be more engaging. In this way the playtime will be increase, therefore, a function to save progress should be added, so that the player can return to the game later.

Longer term aspirations involve expanding the maths content, to include mechanics for further differentiation rules, such as the product, quotient and chain rules of differentiation or even explore how to incorporate different maths topics, like trigonometry. An initial idea involves using a 'trigonometric clock' to measure time by means of the trigonometric circle.

As for higher ambitions, the plans need a group of researchers, designers, and developers to transform this single player game to multiplayer. By using competition, rewards, challenge, and acknowledgement as motivating learning factors, more disciplines can also be introduced, e.g., biology, business, literature, etc. with each following a different path of levelling their knowledge. The various expertise could be used, say, in the mechanics of a group boss fight, similar to the group fights of multiplayer games where the groups need to have a combination of healers, tanks, and damage dealers. Ultimately, the dream is to build the first educational MMORPG (Massive Multiplayer Online Role-Playing Game) which is a difficult task to implement, however it was the inspiration from where the whole idea began.

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