An Educational Game About Math and Magic

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Abstract. This paper presents a mobile game to be played by fifth and sixth grade students during their free time, to improve the knowledge they obtain at school. The game uses a unique story and various interaction mechanisms (e.g., drawing on the screen, tilting the phone) to take the focus away from the educational aspects, so that the players feel like they are playing, not studying. User tests have been performed, showing that most students improved their knowledge and providing feedback for future developments.

Keywords: Mobile game, Educational game, Interaction mechanisms, Shape recognition, Accelerometer.

Introduction

Students spend a considerable portion of their time interacting with their phones. Mobile games are enjoyable for being simple and fun. However, most of them have no educational purpose. Meanwhile, most students struggle with some school subjects and end up losing the motivation to study. Therefore, we decided to create a mobile game that would be appealing while helping to strengthen math knowledge. We aimed at taking the focus away from the educational aspects, so that the players don't feel like they're studying. Math questions are answered in different ways, like leaning the phone, drawing on the screen or even having a math duel with a wizard.

In recent years, there has been more focus on using videogames as a learning method, mostly because of their ability to captivate attention and hold it for long. Educational games use interactivity to transmit knowledge, by requiring players to strategize, test hypothesis, or solve problems. These games usually include a system of rewards to motivate the player, a context to the activities, and learning content [1]. A handheld math facts game [2] for second graders made those who played it solve three times more problems in the same time as those using paper worksheets.

Mobile games recently started being used in support of student learning, both in formal and informal settings [3]. Since these games can be played anytime and anywhere [6], they don't necessarily need to be used in the classroom [4] and have the potential to improve efficiency and effectiveness in teaching and learning [5] while also offering various unique and contemporary learning opportunities and promoting collaboration and interaction between players [3].

These games also help to develop a whole other set of important skills, such as creativity, decision-making, abstract thinking and visual and spatial processing. A study [8] found that students tend to be more motivated to play games that challenge them to utilize higher order thinking skills, where a strong narrative with fitting and tightly coupled learning tasks help motivate players to learn [9], and that giving the player goals of different levels to achieve helps them being more engaged [10].

Game Description

We created a mobile game to be played by fifth and sixth grade students during their free time aiming at reinforcing the knowledge they obtain at school, while using techniques to move the focus away from the educational aspects of the game. We do this by having not only different ways of answering questions, but also by adding decision-making and minigames, which helps the students enjoy playing and also obtain helpful knowledge. We focused on math, because it is a fundamental topic which is not naturally understood by all the students, but the game can be expanded in the future. During the design process we counted with the informal feedback of a fifth-grade student.

In the game, an evil wizard stole all the math in the world and hid in his magic mansion. The player's mission is to find and defeat him. The game consists in walking through the corridors and rooms of the mansion, overcoming the challenges that come up by using different interaction mechanisms. The game ends when the player reaches the wizard's room and defeats (or is defeated) by him in a math duel, consisting in a series of math questions answered by both the player and the wizard simultaneously.

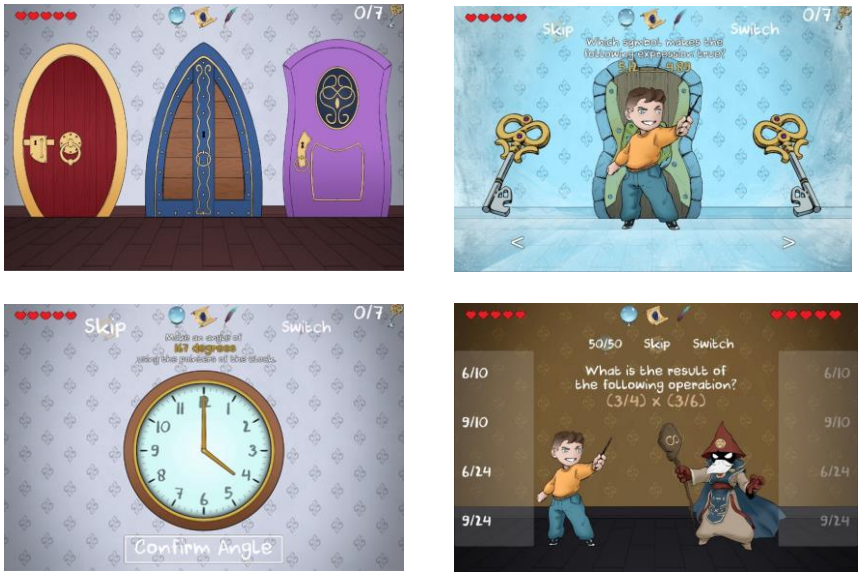

Fig. 1. a) Example Corridor. b) Example Tilting Question. c) Example Clock Question. d) Final Duel.

When the game starts, the player is asked to choose their school year and difficulty level, so the experience is tailored to their choices. By increasing the difficulty, the player will start the game with less lives available, and the evil wizard will become smarter, answering correctly more often during the final duel.

After a short introductory story to engage the player in the context of the game, the player enters the magic mansion through a first corridor (Fig. 1a). Each corridor has three different doors to choose from, each one leading to a different room. The player will find a different corridor every time they leave a room, which helps providing a feeling of choice and variety. There are several kinds of rooms available.

Key Room: In these rooms the player finds a key. The wizard's room is protected by magical wards, preventing the player to find and unlock it until they have all seven keys. In a key room, the player must click the key to collect it.

Question Room: Here the player finds the wizard, who escapes, locking the way out with a spell. To be able to exit the room the player must answer a math question related to a school subject. If they fail, they lose a life. The game has four kinds of questions:

- **Multiple-choice**: A question with four predefined answers from which the player must choose one, with no time limit but only one chance.
- **Drawing:** A question to which the player must answer with a simple character (e.g. a one-digit number) by drawing it on the screen. Time limit of thirty seconds, with no limit of tries.
- **Tilting (Fig. 1b)**: A question with two possible answers. The player must tilt their phone and guide their character to the correct answer.
- **Clock (Fig. 1c)**: A question that requires the player to form an angle with the hands of a clock. The player is able to control only one of the hands, by tilting their phone, while the other hand is fixed.

After answering a question, the player receives feedback about the correct answer. The player then proceeds to another corridor, if they have not lost the game.

Treasure Room: Here, the player finds a chest they can decide to open. It contains one of the following artefacts:

- **Crystal Ball**: Remove two wrong answers in a multiple-choice question.
- **Portal Scroll**: Skip a question.
- **Feather Pen**: Change a question to another of the same kind.
- **Life Medallion**: Grants the player an extra life.
- **Cursed Medallion**: Takes a life from the player.

All the artefacts have the same chance of appearing. The player is only able to carry one of each artefact at a time (except lives) and will keep them until used. The artefacts can be seen on the top center of the screen (Fig. 1c).

Minigame Room: This room allows the player to get an artefact of their choice by completing a minigame. Currently the minigame requires the player to tilt their phone in

order to help the character move and catch potions falling from the sky. Catching the required number of potions within the time limit completes successfully the minigame. These minigames contribute to highlight the entertaining aspects of the game.

When the player obtains all seven keys, the magic wards are broken, and they'll find and face the wizard in a math duel. Both the player and the wizard must answer a series of multiple-choice questions (Fig. 1d). The player starts the duel with the lives they saved during the game, while the evil wizard always starts with full (five) lives. When the player answers a question, the evil wizard answers it too, and each wrong answer makes them lose a life. The wizard uses a simple algorithm to answer a question, where he can either choose the correct answer, or choose one of the answers at random. The chance of choosing the right answer increases with the difficulty level. Whoever manages to survive the longest wins the game.

User Study

To evaluate the game, two testing sessions were performed. The educational effectiveness of the game (through a math test), and the interest and enjoyment of the children were evaluated while playing (through observation, a small questionnaire and an informal conversation).

The first prototype had only one difficulty level, no minigames, no tilting or clock questions, and the drawing detection was not calibrated. Its evaluation provided us with valuable feedback to validate requirements and guide further developments. With this feedback a second prototype was implemented and evaluated, comprising all major features described in the previous section.

Two different classes of sixth-grade students participated in each of the sessions. Both sessions occurred in a classroom and lasted around 1h30m for each class, with a post-session one week later that lasted for 20 minutes. The same methodology was used in both test sessions:

- First the students answered a math test, about their knowledge prior to playing the game. The test lasted for 20 minutes.
- After the test, we let them play the game. The participants installed the game on their phone or tablet and played it for 50 minutes while the research team members moved around the classroom, observing their behaviour and assisting when needed.
- In the end, we offered a questionnaire to fill in and had an informal conversation with them. This lasted 20 minutes.
- We then let them play the game on their own for a week.
- One week later we met again in the classroom to repeat the same math test they had done the previous week, so we could see if they had improved their math knowledge (they had no information the test would be the same, nor did they have the solutions). This lasted 20 minutes.

The test and questionnaire were individual, but the participants were allowed to join their friends and play together, as we wanted them to feel free and act as naturally as

possible. A total of 29 sixth grade students (17 boys and 12 girls) with ages between 10 and 11, from two classes participated in the first evaluation. The test used to evaluate their improvement consisted in 16 open answer questions addressing both fifth and sixth grade subjects (as they were at the end of the sixth grade). The questions were based on subjects in the game. We obtained the following results:

- On average, students increased their scores by 10% and the highest score increased by 12%.
- In a total of 29 students, 20 improved their score after playing the game, while 6 maintained it and 3 lowered it.
- The student with the biggest improvement had an improvement of 44%.

To evaluate the players enjoyment, we gave them a questionnaire with a few questions, using the Smileyometer [11] technique. From the first prototype, we learned that:

- Most students use their phone to play while using their computer to study. This supports our decision of creating a mobile educational game, as they can play on their phone and learn from it.
- When asked about the game, 91% enjoyed playing it, while 78% showed interest in playing it again, which were quite positive results.
- When asked if they had trouble understanding the game, 57% answered "never" or "almost never", while 37% answered "sometimes" and 6% answered "very often". This was concerning, as it meant the interface wasn't as simple to understand as we thought. Thus, we decided to improve it according to the observations and the informal conversations.
- When asked about the game questions' difficulty, 77% found it to be appropriate, so there didn't seem to be reason for concern.

During play time, we observed that while the children started by playing alone, as time passed, they begin to interact with each other, helping their friends or challenging them to a speed run of the game. We also observed that the players were having some trouble with parts of the interface. During the whole session the children were very enthusiastic about the game and eager to collaborate. They provided us with plenty of ideas, like the possibility of choosing between difficulty levels, and the minigames.

The second prototype was tested by 30 students (11 boys and 19 girls) from two sixth grade classes, with ages between 10 and 11. This time we gave them a test consisting of 14 questions covering only fifth grade subjects (as the students were only starting the sixth grade). From this second prototype we obtained the following results:

- On average, students increased their scores by 11% and the highest score increased by 22%.
- From 30 students, 18 improved their score after playing the game, while 10 maintained it and 2 lowered it.
- The students with the biggest improvement had an improvement of 36%.

These results, as the ones from the first evaluation, show that the game was effective at helping students obtain and retain math knowledge. We were not able to relate the

playing time with their performance in the math test, as we couldn´t collect data regarding the students' usage of the game outside the classroom. We can, however, assume they had their usual study patterns during that week, as they had no exams planned.

From the second prototype's questionnaire we learned that:

- Most students use their phone to play. In this case they reported using the computer to play and study, and most of them also used a tablet to play.
- About the game, 96% enjoyed playing it while 92% showed interest in playing it again. These were improvements from the already good results of the first session.
- When asked if they had trouble understanding the game, 84% answered "never" or "almost never" while 12% answered "sometimes" and 4% answered "constantly". This is also an improvement over the first prototype, as now a majority of players seems to understand the game easily.
- When asked about the questions' difficulty, 60% found it to be appropriate. While the percentage of players finding the questions' difficulty level appropriate has gone down, it can be justified as different kinds of questions were added to the game and the increased difficulty that was detected on the clock questions, something we have later improved.
- When asked the participants to sort the various parts of the game in terms of enjoyment, we found out the part that needed more improvement were the clock questions. We also found out that the players seem to enjoy more the parts that don't involve math questions, with the final duel being an exception to this. The favourite interaction was drawing the answer.

Again, the players were very excited, proposing new features to the game, including a labyrinth minigame. We can conclude we were successful in incorporating the educational aspects in a game that is fun while transmitting knowledge.

Conclusions

We created a game with the objective of helping students of the fifth and sixth grades obtain and retain math knowledge, while still having fun. Overall, we obtained good results from the tests we conducted, as a majority of players improved their knowledge after one week of playing the game, and also enjoyed the game. Thus, we can conclude we created a game that shifts the focus to its ludic aspect, while promoting learning. We plan to add new features to engage players as, for example, new unlockable characters to play with, and new kinds of challenges.

Acknowledgments

This work is funded by FCT/MCTES NOVA LINCS PEst UID/CEC/04516/2019.

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