How to Apply Gamification Techniques to Design a Gaming Environment for Algebra Concepts

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Abstract. Applying game-like mechanics in non-game software is a technique known as gamification. Gaming environments have been used to teach mathematical topics such as addition and division in a fun manner. However, given the difficulty of mathematical concepts, especially at the college level, it is very difficult to make software that can be considered both a video game and a teaching tool. Past game work in mathematics has mainly been the creation of puzzle games for primitive concepts such as addition. Our aim with this work is to show how we can build a type of entertainment software that allows users to learn mathematical concepts through play and investigate whether this type of game can help reduce players stress.

Keywords: Gamification · Artificial intelligence · Tutoring systems · Gamifing mathematics' concepts

1 Introduction

Many people struggle when it comes to learning mathematics [1, 2]. It has been shown that video games equipped with intelligent tutoring system tools can significantly improve learners' performance [4–7]. In a previous paper [4], authors showed that compared to traditional and online tutorials systems, gaming environments can be particularly beneficial for learning mathematics at the college level. However, the

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authors only discussed how the quadratic formula can be implemented as a type of puzzle game. That is, the learners must have some background in college algebra in order to be able to solve puzzle games. Learners who have difficulty with mathematics may not be motivated to complete such puzzle games. Furthermore, the explicit introduction of mathematics into puzzle games might increase the learners' apprehension and anxiety level thus preventing learning [8, 9].

While playing a game and learning, it is imperative that the learner remains motivated. Many psychological methods such as the instructionalist and constructivist methods have been used in Intelligent Tutoring Systems (ITS) to keep students engaged and motivated during training sessions [10, 11]. However, one might ask, what shall we do if you are teaching math and your students aren't into it?

In an educational software, to get learners engaged when it comes to the gamification of a concept, most refer to the use of gamification techniques such as leveling up users in the game, as well as using badges and points: increasing the numerical number of your work. However, given the level of difficulty involved in teaching mathematical concepts, additional gamification concepts should also be used[1]. The first and most important criterion is that the learners feel they are playing a game- not solving a mathematical problem. Furthermore, the aforementioned gamification criteria make sense in learning environments in which learners can identify themselves with the game. This should have the feel of a real entertainment environment once they are immersed. Thus, making users forget about math and have low level stress while playing and learning.

In this paper, we show a system that starts with very primitive concepts such as addition and subtraction, and allows learners to learn difficult concepts such as coefficient in quadratic formula. The key component of this work is making an emergent training session. That is, the learner must feel he/she is playing a real game (not a mathematical puzzle to be solved), and become engaged with the game. Once the player's attention is engaged, mathematical concepts are introduced within the game.

Our claim in this work is that to maintain learners' motivation, the following criteria are essential: (1) the game must have elements of fun; (2) there must be a path to the mastery of game: learners receive hints and are prompted about their progress towards short-term and long-term goals. As opposed to ITS, the hints and demonstrations are presented in two parts, (a) hints and demonstrations about how to play the game, (b) hints and demonstrations about how to solve the mathematics problem; (3) challenges must be integrated into the game; (4) There must be competition and feedback: learners constantly know where they stand and where everyone else stands. A slight difference between gaming environment (GE) and Intelligent Tutoring Systems (ITS) for feedback is that ITS uses messages such as hints to motivate, and confirm learners actions. However, GE uses rewarding strategies such as badges; (5) There must be badges: once a player achieves a goal, it is clearly shown together with the score on the main menu of the application; (6) create challenges that do not have only one solution; and finally, (7) a tutoring system must be integrated within the game to intervene and help learners when necessary [4, 12].

[1] https://www.youtube.com/watch?v=qsl9NjyVpHY.

In this paper, we focus mainly on how to use gamification techniques to make learning math fun. Furthermore, our previous work has shown that even when we have a gaming environment that teaches math concepts in a fun way, the users can still have difficulty interacting with the system. So, our goal in this paper is to propose a way to make an environment that is both fun and easy to interact with, making learning emergent. As a first step, we describe how learners who were asked to solve a mathematical problem after using our mathematics computer game, called Flunky Math Mayhem, and reported lower anxiety about mathematics than learners asked to solve the same problem without having used our game first. We consider this a first piece of evidence that our game provides a learning environment for learning mathematics that promotes motivation and enthusiasm in the learners.

In the following sections, we use ITS tools, gaming technology, and artistic animations to create mathematics lessons with which it is fun to play and learn. We show different techniques which can be used to gamify algebra concepts. That is, from very basic and overlooked elements of daily life, one can make learning mathematics fun. In section two, we discuss the gaming environments that were conceived for learning mathematics. In section three, we describe our system (Flunky Math Mayhem), which is conceived to teach mathematical concepts. We then compare learners anxiety levels who use our system with the learners who did not for a given mathematics problem (see Sect. 4).

2 Related Works

Nowadays, game technology and gamification surround our daily life [13]. Games are created as hobbies for children and adults. Governments use them to encourage people to pay their taxes and use public transportation [14–16].

Many researchers and companies have been working on the learning of math using game technology, namely, Goodwin[2] for middle grade math games. Among others, gaming environments such as Math Playground, are shown to be useful for children learning math skills [17][3,4,5]. However, Math Playground lacks tutoring elements. Some of the aforementioned gaming environments also lack scaffolding for learners or they are not fun at all. Khan Academy (KA)[6] covers mathematics among other topics. Yet although Khan Academy uses elements of ITS (i,e., hints and gamification such as badges), it lacks fun components [2]. Indeed, those training sessions do not use video games and include few or no elements of fun.

Immersiveness is very important in our discussion because it is one of the most important steps that make learners get attracted to the gaming environment. Once

[2] http://www.mangahigh.com/en-us/.

[3] http://www.mathplayground.com/.

[4] http://matematika.hrou.cz/.

[5] http://www.ixl.com/.

[6] https://www.khanacademy.org/.

learners start playing the game, it automatically leads them step by step through the training session to help to achieve designed goals for this session.

When a mathematical concept is gamified, the gaming environment must help learners make associations between the gaming elements, aspects of the non-game activities, *the learners' own goals and the learners' own desires* [18]. To our knowledge, for higher- level mathematical concepts (i.e., quadratic formula such as[7,8,9]), gaming environments have failed to make learning and practicing mathematical concepts fun for students. This is in part because the current ITS lacks the gaming and artistic animation tools that can help designing fun lessons and fun interactions [4]. Therefore, to design and implement the Flunky Math Mayhem environment, we followed the following major steps:

(1) For each specific mathematical concept, we identified corresponding possible solutions and the various ways that the concepts could be taught in fun ways.
(2) For each concept and lesson, we designed gaming environments and elements for real games (i.e., Flunkys Fig. 2). To cover different concepts, we drew from different video games and movies. We also considered the narration of the game. That is, the game played in the first level must be coherent with the games played in the more difficult levels.
(3) For each concept, the lessons and solutions were discussed from an artistic point of view: artistic and real life examples were used to make the lessons' concepts fun.
(4) The psychological component of the lesson: we found real life entities that can be associated with every math concept and lesson.
(5) We integrated the gaming environment and ITS' tools that track users interaction and intervene when needed. For more work please read [4].
(6) We integrated gamification tools such as badges and scoring.

In the next section we describe the Flunky Math Mayhem game.

3 Flunky Math Mayhem[10] Description

Given that this paper focuses on how using gamification techniques can be applied to gamify both simple and upper-level mathematical concepts, in this section, we very briefly mention two different levels of our games: (1) simple addition; (2) first step to solve quadratic formula- identify coefficients such as a, b, c in a quadratic formula. It must be noted that we have implemented other concepts such as subtraction, division, fractions, factoring in a quadratic formula, etc. But for the sake of this paper, we will only explain these two concepts in our Flunky Math Mayhem game.

[7] http://www.mangahigh.com/.
[8] http://www.coolmath.com/.
[9] http://www.onlinemathlearning.com/.
[10] https://github.com/joseffaghihi/GamificationAlgebraConcepts.

In the following we will explain how we implemented two different levels of our Flunky Math Mayhem.

The main characters of our games are Flunkys, inspired from the Despicable Me movie[11].

Addition: The storyboard for this game is that Flunkys must escape a doomed island and make it on the boat (Fig. 2). In this scenario, Flunkys need to be trained and get ready for this adventure. In the first level (Fig. 1), they are embarking on a quest that will determine the rest of their lives. The Flunkys must train to be one of the few Flunkys that will be allowed on the boat. Only the fit Flunkys can escape the clutches of what is to come:

- Getting flicked off the ladder to climb
- Being faster than the other Flunkys so they won't be left behind

In this scenario, only the strongest can survive. Just like the Flunkys must train, the player must train. This level will test the player and the Flunkys quick wit to be able to quickly solve for x. Importantly, knowing how to solve for x is one of the first steps in knowing how to solve a quadratic equation. For the simple addition level (Fig. 1), while Flunkys run on a treadmill, there are bulleted numbers thrown towards them. Using up-down and left-right arrows, learners must help the Flunky avoid the wrong numbers by tilting to the left or right. However, when the right numbers come (numbers for the equation), the learners must make the Flunky collide with it. When this happens, a firework with noises is released and the learner is rewarded. On the left top part of the screen (Fig. 1) the formula appears. On the right side, the learner's life indicator demonstrates how many lives the learner has left. It must be noted that this environment is firstly created to make players play and avoid numbers. Again, the learners first try to learn how to make Flunkys run faster and tilt to left or right to save them. After a while if users cannot get the right answer the numbers spawning rate will decrease and finally a demonstration will be shown to explain the addition concept before the user can restart the game.

Coefficients in Quadratic formula: To start his level, we have created a boat (Fig. 1. B). Once this level loads, a quadratic formula is shown to the learners. The learner needs to find out coefficients a, b and c in the formula. At this point, Flunkys who were saved from the previous levels, are automatically spawned in the scene and try to go up to the ladders that are laid on the boat. There are two types of Flunkys that try to conquer the boat. The right numbers (good Flunkys) who were saved from previous levels and the wrong numbers (bad Flunkys). Getting bad Flunkys in the boat will make it sink and good Flunkys will not be able to escape from the island. The game encourages players to save the good Flunkys and the boat by flicking off the wrong Flunkys. That is, the player is a hero who tries to save good Flunkys from falling off the boat. Our goal when creating the challenge of the game was for it to be simple to play, in the essence of a popular game at the time called Flappy Bird.

[11] *"A 2010 American 3D computer-animated comedy film from Universal Pictures and Illumination Entertainment that was released on July 9, 2010 in the United States." Wikipedia.*

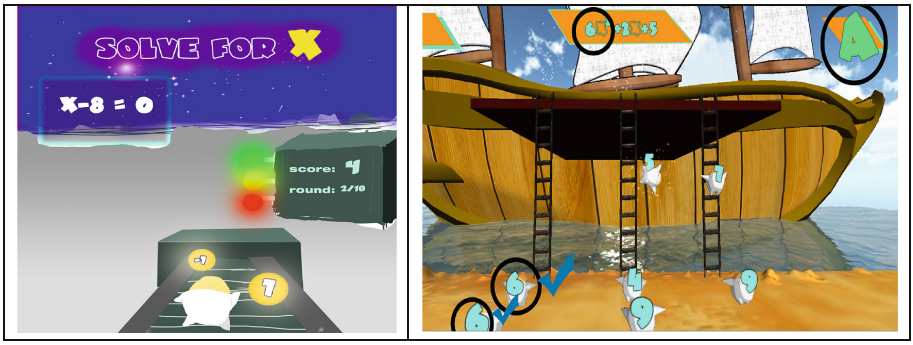

Fig. 1. (A) A Flunky runner on a Treadmill; (B) Finding the coefficients a, b, and c in a quadratic formula. The learner needs to let right numbers get to the boat by clicking on the wrong numbers.

To understand what the learner is doing at each moment, we made a parser for learners' activities. Time for solving problems is very important. Because each problem must be solved in a specific time frame, the timing to solve each problem is decided according to average time learners clicking on the Flunkys. If learners are slow in their first click, the Flunky spawning modules spawn Flunky at a lower speed. As the user improves, the game speeds up.

Finally, if the user misses the correct Flunkys, an animation that explains the quadratic formula automatically appears on the screen to help students understand a, b and c in a quadratic formula (Fig. 2). Thus, based on the learners' performance, the system assigns a score, give hints, presentations, changes some specific fonts, plays an audio file, blinks buttons or levels up the user.

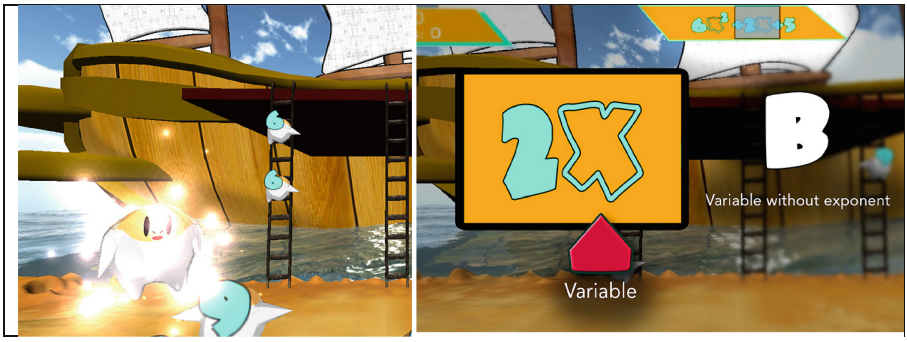

Fig. 2. Left side show the spirit of the Flunky who appears when learners needed help. The right side shows the explanation of coefficients in a quadratic formula.

In Flunky Math Mayhem, a learner can start each level with one or more animations that teach a lesson about, for example, how to use the game (Fig. 3) or the quadratic formula: Learners are free to follow the lesson, which is a fun animation (Fig. 3), or start playing with the game and solve the problems [3, 5–7]. Below, we briefly describe learners' outcome at a quadratic formula question either after playing our game, or not.

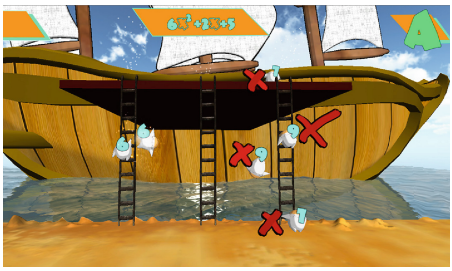

Fig. 3. An animation that show how to play the game.

4 Educational Game Evaluation by Users

Our long-term goal is to reduce the anxiety level of the learners who interact with this education game. As a first step, we asked adults attending a computer science workshop at Cameron University to participate in a pilot test. Fifteen individuals agreed to participate. Participants were randomly divided in two groups. Group A was told that they would have to solve a quadratic formula problem following a 15 min waiting period. Group B was told that they would have to solve a quadratic formula problem after having played our educational game for 15 min.

Following these instructions, we asked all participants to report their anxiety levels using a simple scale of −100, −50, 0, 50 or 100 (−100 extremely anxious to 100 not anxious at all). After completing the mathematical problem, we asked all participants to report anxiety levels again.

As can be seen in Fig. 4, all participants reported anxiety after having been informed that they would have to solve a mathematical problem (pre-test). However, participants who were asked to play our educational game prior to solving the problem reported significantly lower anxiety after having solved the problem. (Post-test; $p < .05$).

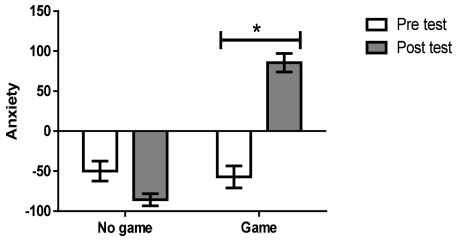

Fig. 4. Anxiety reported prior to mathematical test and after.

5 Conclusion

Video games can use gamification tools to foster learners' confidence when it comes to learning difficult topics such as mathematics [4]. They are also able to present various approaches to solve a given problem. Although many gaming environments exist to teach children mathematics, no such game exists to bond primitive mathematics concept to college-level math. Furthermore, for students who have difficulty with mathematics, even the word *a math gaming environment* may trigger a discouraging feeling in a training session. In this paper, our aim was to bring an environment that is a real game. Learners become engaged with the story board of our game, starting first with basic difficulty levels toward more difficult college algebra such as quadratic formula. Our very first primitive results proof-of-principle results are promising and demonstrate that this idea is worth pursuing. Another future aim would be to test larger sample of participants with our game, comparing anxiety levels and performance of participants who use Flunky Math Mayhem and ITSs' systems such as AutoTuror Lite[12].

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