# Designing a 2D Platform Game with Mathematics Curriculum

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**Abstract.** New technologies and media aim at triggering student interest in mathematics and at making learning an entertaining process. However, playful math games need to provide learners with a better experience, which is connected with an engaging gameplay. Popular game mechanics could be used in order to integrate learning in the playing activities. This research employs the Super Mario game format for the design of a playful educational serious game in the context of math education. Mario Maths is addressed to students of 12 and 13 years old and aims to the practice of divisibility criteria. Mario collects numbers instead of coins that must be exactly divided with the number - target, avoiding or eliminating the wrong answers. A wrong choice transports Mario to a subterranean world which informs him for his mistake, but with no influence on the final goal achievement according to a constructive error and trial method. In the end of each track, the player is taking feedback of his effort in a self-assessment process. Mario Maths was developed to be used as a complementary educational tool for students who might be attracted from such forms of media. (https://github.com/ionio-seriousgames/mario-maths).

**Keywords:** Educational serious games · Math games · Game design

## 1 Introduction

Math curriculum could be enhanced through various educational media, such as math games for practicing trivial tasks, virtual environments for try-out, simulations for making conjectures, strategic games for manipulating & combining, visualizations of structure(s), or explorations in 2D and 3D geometry [7]. Moreover, real problems could be employed to contextualize math education, such as money calculation or x and y coordinates location on a map. Many math games rely on the puzzle gameplay mechanics, e.g. Tic Tac Toe or they apply a separate set of questions to be answered beyond the gameplay mechanics, e.g. Up, Up, and Away [13]. Another approach uses multiple-choice questions which unhide parts of a hidden picture with math cartoon [2] while Angle Jungle game provides a series of puzzles for practicing angles on ipads [14]. However, different game genres could result in different learning outcomes depending on different gaming experiences [4]. Therefore, playful math games are tightly connected to the applied gameplay. According to Guardiola [11], gameplay could be defined as "all the actions which are performed by the player, influencing the


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outcome of a game situation in which he is engaged in. Similarly, Fabricatore (2007) defines gameplay as "the set of activities that can be performed by the player during the ludic experience, and by other entities belonging to the virtual world, as a response to the player's actions and/or as autonomous courses of action that contribute to the liveliness of the virtual world". The gameplay influences users' experience through several mechanics which are "atomic rule-based interactive subsystems capable of receiving an input and reacting by producing an output" [8]. From this viewpoint, popular video game formats could be used for the design of playful math games [3]. Although game designers have employed formats of several game genres e.g. the Motion Math which is a Tetris inspired game [18] or the Gem Game which is a side scrolling platform game [10], the integration of leaning in the gameplay mechanics is still a real challenge. Therefore, more research could be conducted on how math curriculum could be effectively integrated in popular game mechanics resulting in playful math games.

Our intention is to be inspired from a popular video game format and to employ its methods for getting players to learn. Super Mario Bros is a popular run and jump platform game, providing an adventure on two-dimensional levels. In particular, the player can move his avatar from left to right avoiding obstacles and interacting with various game objects. Mario can jump, run or shoot fireballs against his enemies being in three different states; small, big, or fire [17]. Various elements of Super Mario Bros gameplay could be employed in order to integrate educational content, such as the divisibility criteria.

The rest of the paper is structured as follows: in the next section Methodology is described, followed by the Discussion and Conclusions section.

## 2 Methodology

Fabricatore (2007) argues that the gameplay is the most important pillar of the game design activity due to its connection with the player's experience. Our intention is to apply the Super Mario Bros gameplay in the design of Mario Maths, providing players with challenge, mastery and reward to sustain and enhance motivation and entertainment. Mario Maths could be used as a complementary educational tool for practicing the divisibility criteria, a course that is taught in the 6th grade of Greek Elementary School and in the 1st grade of Greek Medium School. The most common method for determining divisibility is to perform the process of division. The divisibility criteria could be alternatively used in order to determine divisibility with not much calculation [21]. Students learn and practice the rules of divisibility in order to advance in more complicated calculations. Therefore, students learn the content and then practice their skills by determining the divisibility of various numbers by 2, 3, 4, 5, 8, 9, 10, 25, and 100 [22]. Drill and practice methods could be used from students in order to acquire such skills through disciplined and repetitious exercise which is the "building blocks" of a more meaningful learning [15]. However, the integration of the curriculum in a popular gameplay could make the learning activity playful while additionally learners are encouraged to construct their knowledge, using various game elements. As a result, the game world becomes an educational environment which supports active and self-regulated learning, according to the constructivist perspective [12]. Game designers and educators worked together, designing a playful math game.

### 2.1 Designing Mario Maths Based on Familiar Gameplay Mechanics

According to Loguidice and Barton [16], Super Mario Bros provides players with the task to save Princess Toadstool from the evil Bowser, the king of the Koopas. The game has one or two players mode and the playable characters are Mario or Luigi. The player is assigned with the mission to complete each board before the time runs out. If Mario fails, he loses a life and must restart the board. Similarly, we designed Mario Maths as a game aiming at learning the divisibility criteria. The game can be played from one player each time, using one playable character, Mario or Luigi. The player's mission is to find the key and unlock the exit door, at the end of each track by collecting 10 numbers which can be divided exactly with the chosen number (See Fig. 1).


**Fig. 1.** Mario needs to find the key and unlock the exit door

Mario is free to explore the game-world till no correct numbers are available. The game provides 4 tracks for the numbers 2, 3, 5, and 10. After the end of each track Mario can restart it with the same or another number. During the game, the player collects numbers according to the different each time divisibility criteria in the same way that coins, mushrooms, fire-flowers, and star-men are collected at the Super Mario Bros (See Fig. 2).


**Fig. 2.** Mario must collect the numbers which can be exactly divided with the number 3

Similarly, to the Super Mario Bros, the enemies to be defeated by the player are Koopas, Mushrooms, and numbers which cannot be divided with the target number (See Table 1).


**Fig. 3.** Game Enemies. a & b: Koopas and Mushrooms are natural enemies used similarly to both games. c: The player needs to collect number - coins which are divided exactly to the number - target. The numbers' shape resembles that of coins in Super Mario. The number is an educational enemy in case that it is not divided exactly with the number - target.

Moreover, Mario attacks the enemies similarly with the classic platform game, jumping on top of them or shooting them with fireballs. Natural enemies, such as Koopas and Mushrooms take him to a previous point of the track depending where he is. Moreover, Mario can jump and destroy blocks, uncovering hidden information. Besides defeating enemies, Mario must navigate his way over and under obstacles. Getting or falling into the sea or into lava will result in losing a life (See Fig. 3).

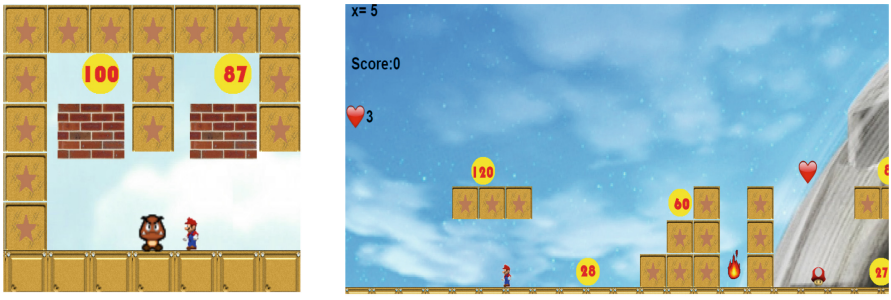


**Fig. 4.** Mario's navigation in the game-world, collecting numbers, avoiding/eliminating enemies. a. Mario loses a life and goes back when touching enemies from the side. b. Mario loses one life when touching the fire or the mushroom

The feature of teleportation also exists in Mario Maths, allowing the character to instantly travel from one part of the stage to another. Finally, important "statistics" are visible to the player, such as the point score, number of lives as in the classic Super Mario Bros (See Fig. 3).

## 2.2 Integrating Learning in the Playing Activities

Mario Maths is designed to be used as an educational tool for teaching math curriculum. Therefore, we describe the core learning mechanics using a flowchart according to the Gameplay Methodology [8]. Dark blue shapes are used to represent the In-Game Actions and the light blue shapes the Out-Game ones which are related to the learning process (See Fig. 4).

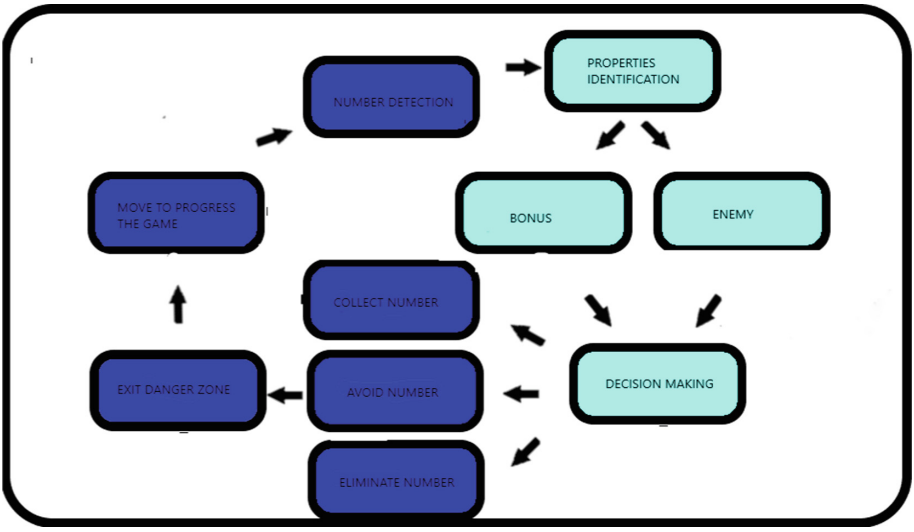


**Fig. 5.** Learning integrated in the playing gameplay [8] (Color figure online)

Player comes to decide if the number he finds on his way is exactly divided with the number - target in order to decide if this number is an enemy to be avoided or eliminated or a reward to be collected.

In Super Mario Bros, subterranean worlds are self-contained areas that offer coin rewards. In Mario Maths, a subterranean world is accessible each time the player collects a wrong number and its purpose is to inform player about his mistake. If the player collects a wrong number, the user will be moved to a new track (See Fig. 6).

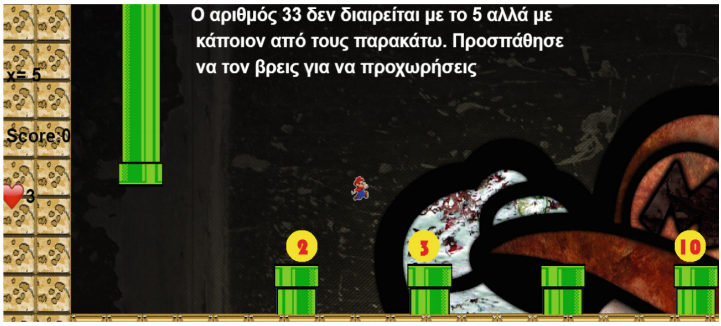


**Fig. 6.** Educational subterranean world

There, the player will be informed that the number is not divided by the number he chose to play. Within this new track, there will be the remaining three numbers and the user will have to choose the right one. Once he has chosen the correct number, he will be transferred to the spot on the main track and will be able to continue his course. An educational message is displayed informing the user about the rule to learn from his errors (Fig. 6).

Finally, there is an educational rewards system when the player collects the right numbers or eliminates the wrong ones (See Table 1).

**Table 1.** Rewards system. The player is rewarded when he collects numbers that can be divided with the number - target and when he eliminates numbers that cannot.

| | Score | Life | Extra number |
|---|---|---|---|
| Collects 1 correct number | √ | | |
| Collects 5 correct numbers | | √ | |
| Eliminates 1 wrong number | | | √ |
| Eliminates 5 wrong numbers | | √ | |

As the player progresses through the game's levels, he encounters a lot of numbers that may or may not divide exactly the number they have chosen to play with. Choosing a correct number will increase the score by a hundred points. At the same time, the player comes one step closer to finding the key. Also, if he finds five correct numbers, then he will earn a life as an educational bonus. If while using the shooting ability, the player eliminates a wrong number, then it will win a life and if it manages to eliminate five, then a more correct number will be displayed at the end of the track.

### 2.3 Educational Results

Although the Mario Maths goal is to collect 10 correct numbers – coins to find the key, the player is encouraged to explore the world in order to achieve better educational results in the end. When the user touches the key or the door, the track ends and a screen with its educational results is displayed. Through this screen the player is informed of the number of correct and wrong choices, the number of total available options and what his wrong choices were specifically. Therefore, educational results appear to the player regardless of his performance. This is how learning analytics were used and the player can see his overall effort in numbers at the end of each game track as learning analytics involve the collection and analysis of student effort [6]. Students expect that learning analytics could be used to support the learning process, providing self-assessment, delivering recommendations, and producing personalized analyses [19]. On the same screen there is a button that allows the user to start the track from the beginning if he so desires. Finally, the game may also end when the player has no other available lives, where in this case he will be informed of his educational results.

### 2.4 Introductory Scene

The introductory screen of the game features two buttons, labeled 'Play' and 'Controls'. 'Play' button begins the game, while 'controls' features information about the control of the game. Choosing the 'play' option, will lead to a screen which will inform the player that in order to win the game he/she must select ten numbers that will be divided exactly by the number he has to practice. This will result in finding the hidden key that will "unlock" the door to exit the level. Also, the screen informs the user, that whenever a correct number is chosen, this will be displayed at the top of the screen. The use of the shooting function is also mentioned, to avoid the wrong numbers but also to get rid of other enemies on the screen. The last thing mentioned is the feature of teleportation that exists in game, making it possible for the character to instantly travel from one part of the stage to another. At the end of the instructions the player is prompted to choose between Mario and Luigi to start the game, as well as the number he would like to practice with. The available numbers are 2, 3, 5, 10 and the player's goal is to find the numbers that are exactly divided by the number they choose. A skip intro button is also provided, and if pressed the player is transported directly to the player and number selection screen. In-game, information is displayed on the top of the screen: the number of remaining lives, the score, and the number that the player has chosen to practice with.

### 2.5 User Interface and Game Controls

As in traditional Mario Games, Mario and Maths features a traditional side-scrolling, 2D view. Score and lives are displayed at the top left of the screen, and Mario (or Luigi) can move left or right, jump, with the use of arrow keys on the keyboard, or fire, using the spacebar.

### 2.6 Game Aesthetics

The aesthetics of the game are an important part for the game's success in communicating with the players. The backgrounds that appear in the narrative and on the slopes have been chosen to match the character of Super Mario. Also, all the numbers along the track are shown through yellow circular frames so the user can not only see them, but also remind them of the Super Mario coins. Finally, several images have been added to various screens, messages and game elements to make the user's environment more friendly. Music is also added to the game as well as "point sounds" whenever something important is happening. Events that might trigger sound effects are the right or wrong choice of number, contact with an enemy and the use of the elevator and the propeller.

### 2.7 Development

For the development of Mario and Maths, the Phaser tool was used because it contains important functions for the video game development. Also, the Tiled tool was used for the design of the game track. It has also been chosen the JavaScript and the HTML programming languages for designing a video game which runs on the Internet.

On the contrary with most educational serious games, we do not only provide the game online on the internet for students and teachers to use it, but additionally, we developed Mario Maths as an open source educational serious game, available on the internet for modifications/improvements. This transparency is aiming at supporting innovation, knowledge sharing, and community building [5].

## 3 Discussion and Conclusions

This study aim is the design and development of a math game to be used complementary as an educational tool for those students who find attractive such type of educational media. The design process was based on the gameplay mechanics of a popular video game in order to provide players with a joyful experience. We were inspired by Super Mario Bros methods for getting players to learn. Designers of good video games employ effective methods for getting people to learn long, complex and difficult games, in a joyful way [9]. We carefully integrated the educational content in the Super Mario Bros mechanics, preserving the entertaining parameter of the game. Super Mario Bros is a video game with a significant educational value; players must learn to jump between platforms, break blocks to get points and power ups or eliminate enemies, such as Bowser, Koopas, and Boos. Moreover, players need to solve problems and puzzles during their navigation in the game world. As a result, Super Mario Bros is considered a fun and engaging game [1]. The use of Super Mario Bros popular elements, such as the characters and the way they move inside the game world, advancing the game and defeating their enemies was aiming at making Mario Maths an appealing game that embeds math curriculum. We integrated content that is addressed to students of 12 and 13 years old, for practicing divisibility criteria. Therefore, Mario collects numbers, instead of coins, which must be exactly divided with the number - target and avoids or eliminates those ones which are not. Following Super Mario Bros format, the player needs to unlock the track's door instead of saving Princess Toadstool, using Mario or Luigi. All the gaming activities of Mario Maths exist in the Super Mario too. The player attacks the enemies, jumping on top of them or shooting them with fireballs or jumps and destroys blocks, uncovering hidden information. Teleportation is a game element that also exists in Mario Maths too and instantly travels the character from one part of the stage to another. "Statistics", such as the point score, number of lives are displayed on the screen in the same way. However, all this gameplay embeds learning activities (See Table 2).

**Table 2.** Super Mario Bro and Mario Maths gameplay

| Super Mario | Mario Math |
|---|---|
| Entertainment | Entertainment + learning the divisibility criteria |
| The player needs to save Princess Toadstool from the king of the Koopas | The player's need to find the key and unlock the exit door |
| One or two players mode/Playable characters: Mario or Luigi | One player mode/Playable characters: Mario or Luigi |
| Each board must be completed before the time runs out | Each board must be completed according to the educational rules. |
| If Mario fails, he loses a life and must restart the board | Mario is free to explore the track till no correct numbers are available. After ending a track, Mario can restart the track with the same or another number |
| The player collects coins, mushrooms, fire-flowers, and star-men | The player collects numbers according to the different each time divisibility criteria |
| Enemies to be defeated by the player are Koopas, Boos, and Mushrooms | Enemies to be defeated by the player are Koopas, Mushrooms and numbers based on the educational rules |
| Subterranean worlds are self-contained areas that offer coin rewards | Subterranean world are accessible each time the player makes a mistake in order to learn |

Therefore, players construct their knowledge, using the various elements of the game world. Finally, we adopted a constructive trial and error method in order to encourage players in achieving the learning purposes, an element that exist in similar educational games, such as the gem game [10]; when the user makes a wrong choice, he is not punished but he is informed of his error and encouraged to continue trying [3]. Nevertheless, this cannot influence the social meaning of a rewards system as the final statistics allow players to use it for purposes of comparison and social interaction [20].

The current version of the game offers the ability to learn the divisibility criteria with numbers 2, 3, 5 and 10. All the game is progressing to a basic track and the user has the option to choose the number with which he wants to practice before the beginning of the game. However, in the future, more numbers could be added to the game, in order to increase the difficulty. A further meaningful expansion of the game could build on this math curriculum, providing more complex educational activities aiming at extending and enriching student understanding. Finally, we are planning to evaluate Mario Maths, in terms of learning and entertainment in the formal school settings for potential improvements.

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