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Article

Mathlien Land: a serious game to practice 7th and 8th grade mathematics

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Abstract

The use of educational serious games has widely spread in recent years, addressing several topics and purposes. A common target of these tools is science subjects, particularly mathematics, as it is one of the most commonly difficult and stressful subjects for students. After reviewing available mathematical educational games, we found a gap in games that target the mathematical content of the first cycle of secondary education (7th and 8th grade). Consequently, in this paper, we present Mathlien Land, an educational serious game to teach mathematical concepts to 12 to 14-year-olds. Through six independent but unified minigames, the game allows players to practice the main content of secondary mathematical courses within a playful environment. We also present the results of the early testing of the game with both general participants (N=17) and specific target users (N=40) for usability, opinion, and usefulness, obtaining positive feedback for all minigames and the overall game, as well as some areas of improvement such as the translation of the game to other languages. After this early evaluation, we plan to continue testing the game in other contexts and include analytics in the game to obtain more refined information of the learning process of players.

1. Introduction

Technology is becoming increasingly present in everyday life, a use that particularly affects young people [1]. Although this excessive use of technology can lead to various problems, it also provides an opportunity to fight against school failure in the educational field, using the new tools available to encourage curiosity and learning. It is here where concepts like gamification or educational games become particularly important by providing a way to combine learning with entertainment using tools widely used by students [2], [3].

This opportunity can be particularly useful in traditionally difficult subjects for students, such as STEM (Science, Technology, Engineering, and Mathematics) subjects, as introducing game elements can help relieve the anxiety caused by their study and facilitate learning more playfully [4].

As such, gamification has been incorporated into educational scenarios through several platforms and tools. Serious games or game-based learning techniques are one of them, and they have already been applied successfully to different educational subjects, including, but not limited to, mathematics, physics, medicine, language, etc. [5]. In many of these experiences, serious games are meant to be played within the classroom, with teachers' supervision, or as a tool to review and complement teachers' tasks. They can also be used as independent tools for students to review concepts learned in class.

In this article, we present Mathlien Land, a serious game to teach mathematics to secondary students by providing minigames to review the most common mathematical content of those educational years. We also present the results from its early usability and acceptance evaluation with both a group of the general population (N=17) and a specific group of students in the target group (N=40).

The rest of this paper is structured as follows: Section 2 reviews some background on serious games in general and for mathematical teaching in particular, and presents the knowledge gap found and the objectives of this study; Section 3 presents the materials and methods, including the game developed, the questionnaires used for its evaluation and the participants in the evaluation study; Section 4 describes the results obtained in both evaluations, which are then discussed along with the study limitations and future lines of work in Section 5; finally, Section 6 summarizes the main conclusions of this study.

2. Background

2.1 Serious games

Serious games are defined by an objective beyond entertainment, seeking to be useful for the practice or acquisition of knowledge [6]. Serious games mainly focus on the learning objective, facilitating the user to achieve it in the best possible way. The game's elements (e.g., the story, and characters) should not distract the user from the learning process. Likewise, a positive and entertaining experience should be ensured, guaranteeing a balance between the user's possibilities and the proposed challenges and allowing the user to control the game, to generate positive emotions associated with learning and the desired feeling of self-satisfaction [7]. It is important to balance within serious games the learning component with the pure game elements or gamification, which consists of the use of components typically associated with games such as rankings in other environments to encourage user participation [8].

Serious games have been applied to many domains (military, medicine, education) and with multiple purposes (learning, creating awareness, changing attitude) [9]. The so-called educational games, that is, serious games focused on teaching something to their players, are only a particular case of the broad landscape that serious games cover. Educational serious games have been applied to multiple learning fields, with a particular focus on STEM subjects [10], [11].

2.2 Mathematics and game-based learning

When it comes to learning, STEM subjects are commonly mentioned as some of the most difficult and stressful subjects for students of all ages [12]. As such, the application of game-based learning has been widely applied to these subjects, with many examples of games to address science, technology, or engineering subjects [13], [14], [15].

Mathematics does not fall behind; quite the opposite, it is well-known as one of the most difficult subjects for students of all ages [16]. As such, there are several studies using videogames for mathematics mainly for primary education [17]

Existing games exist to teach mathematics, including DragonBox Elements [18], Mathland [19], Themathgame [20], Mathbreakers, Treefrog Treasure [21], Mental Maths Train,[22] Archery Arithmetic Multiplication, [23] Hit the Button [24], Arithmetic Game [25], and Alien Addition [26], also seem to focus on primary education, where the basic operations and content of mathematical learning are established.

2.3 Knowledge gap

After analyzing several educational games about mathematics, including the ones mentioned above, we found out that most of them are designed for children between 5 and 12 years old and focus on topics such as addition, subtraction, multiplication, division, and other topics such as number lines, factoring, fractions, negatives, and prime numbers. However, to the best of our knowledge, we found no games that target an older audience, that is, students of secondary education (12 years of age and older). Recent literature reviews regarding mathematical learning games also point out, among their results, the fact that most games are targeted to primary education [27], [28]. To fill this gap, we propose to design and develop an educational serious game that covers the mathematical content of the first cycle of secondary education, that is, for students between the ages of 12 and 14 years old.

2.4 Objectives of the study

This study has three main objectives:

O1. Present the serious game Mathlien Land, including its educational goals, design and development, and the mathematical concepts addressed in it.

O2. Evaluate the usability of the game Mathlien Land through a survey conducted among the general population, also testing the game for any possible bugs or improvements.

O2. Evaluate the acceptance and usability of the game Mathlien Land through a study with students of its target group (12-14 years old).

With these objectives, we aim to provide a general early acceptance evaluation of the game, as well as to obtain feedback and improvements to continue updating the game.

3. Methods and Material

In this study, we aim to test the design and development of Mathlien Land, an educational video game to teach mathematics to students in the first cycle of secondary education (12-14 years old). With the completed version of the game, we conducted an initial survey among the general population to test usability and acceptance, and an early study with end-users consisting of full gameplay, playing all 6 minigames of the game, and a post-game questionnaire. The following sections present in detail the serious game Mathlien Land, including its design and development; describe the questionnaires used for both the general population survey and the evaluation study; and present the characteristics of the participants in both studies.

3.1 Mathlien Land

The game Mathlien Land aims to be an educational support tool for teachers by allowing players/students to review and practice the mathematical concepts learned during the first cycle of secondary education (12-14 years old). For that purpose, we first identified the mathematical topics common for those two academic years, which were six topics: fractions, proportionality, divisibility, decimal metric system, graphs and functions, and integers.

As the six topics to be included in the game were varied, we decided to better divide the game into six independent minigames, each of which explores one of those mathematical concepts. With this structure, it would expand the possibilities of game application, as it could

also be used in class just to review one of these topics, by simply accessing and playing the corresponding minigame. Despite being independent, all minigames would follow the same theme, structure (initial and end screens), and visual elements so that there would be coherence between all six minigames as part of the full game.

The content of the game (menus, instructions on how to play, questions to be answered, explanations of the mathematical content given after solutions) was written in English to broaden its possible reach. Considering that the schools in the country to be tested (a non-English speaking country) had many bilingual classes, the English capability of students in secondary education was expected to be sufficient to understand the game instructions and the mathematical concepts included in it with no difficulties.

The design of the game included simple mechanics for each minigame, using some common game genres and mechanics well-known to players so that their focus would be on the mathematical content to learn/review/practice, and not on the game mechanics.

The game was developed using Godot Engine [29], a free and open-source engine to develop 2D and 3D games. All minigames are developed as independent modules, following the same structure and using common utils so that the game is easily maintained and extensible. Visual elements and sounds included in the game were free to use from several open-source websites [30], [31], [32], [33], [34].

Figure 1 shows the main screen of Mathlien Land (left). Entering the game displays the main menu, with all 6 minigames available to be played (Figure 1, right).

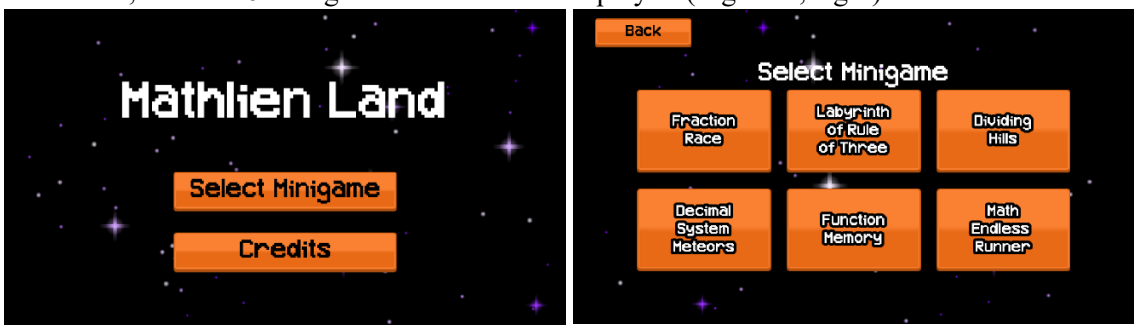

Figure 1. Main screen of Mathlien Land (left) and minigames menu (right).

Table 1 presents a summary of the six minigames included in Mathlien Land. The design of each minigame is briefly described in the following sections.

Table 1. Summary of minigames included in Mathlien Land

Minigame name	Mathematical topic	Mathematical concepts	Game genre/mechanics
Fraction Race	Fractions	Addition, simplification, and equivalences	Racing
Labyrinth of Rule of Three	Proportionality	Direct and inverse proportionality	Labyrinth
Dividing Hills	Divisibility	Divisibility criteria	Infinite racing
Decimal System Meteors	Decimal metric system	Conversions between measurements	Asteroids arcade
Function Memory	Graphs and functions	Association between them	Match pairs of cards
Math Endless Runner	Integers	Addition, subtraction, and multiplication	Endless runner

3.1.1 Fraction Race

On Fraction Race, players review the topic of fractions by participating in a race between four players. One of the cars is controlled by the user, while the other three cars are controlled with movements dictated by the system. All of them maintain a constant speed during the race by default, only altered by accelerations. These accelerations occur randomly for the cars controlled by the system. For the car controlled by the user, these accelerations depend on the correct answer to a multiple-choice question belonging to the "Fractions" topic. The question appears on the top part of the screen, and it provides 4 possible answers. When choosing an incorrect answer, nothing happens. When choosing the correct answer, the car controlled by the player accelerates, and the question changes to a new one. The goal of the minigame is to win the race, which can be done by answering more questions correctly (therefore, accelerating more than the other players). A help button is available on the top-right corner of the screen. When pressed, it stops the race and shows a summary of the content regarding fractions for players to review before continuing playing the minigame.

3.1.2 Labyrinth of Rule of Three

Labyrinth of Rule of Three consists of a labyrinth populated by enemies with four possible exits. On the top part of the screen, a question is shown to the user related to the content of the "Proportionality" topic. Each exit of the labyrinth, situated in one of the four corners of the screen, displays a possible answer to the question. Only one of the exits displays the correct solution to the question. Learning by error is encouraged as selected exists with incorrect answers will be closed, to eliminate possible repetition of errors by the user. Once a question is answered correctly, a short explanation appears detailing the process to reach that conclusion. After that, the character will appear again in the center of the labyrinth and players will be presented with a new question. The goal is to answer correctly 5 questions to complete the minigame and successfully exit the labyrinth. In this case, the pause button only stops the minigame in case players need more time to calculate the solution (e.g., on paper).

3.1.3 Dividing Hills

In Dividing Hills, players' goal is to advance as far as possible in an infinite hill path. While moving along the game, players should also collect as many coins as possible. Gasoline needs to be consumed to be able to move the character. For that, there are points along the path that allow players to obtain gasoline. When one of those points is reached, a question related to the "Divisibility" content appears in the screen. If answered correctly, players can refill the gas tank and continue. If they fail, players can only continue if they still have some gasoline. If not, the game is over. Another element that added to the difficulty was the inclusion of the ability to roll over so that bad driving can also result in a failed game. The goal of the minigame is to advance as much as possible while collecting coins. The pause button in this minigame also provides some help by showing the divisibility rules for integers between 2 and 11, for players to be able to revise them before continuing playing the game.

3.1.4 Decimal System Meteors

Decimal System Meteors belongs to the Arcade genre, and it consists of controlling a traveling alien in space. The alien must evade the meteorites that present a danger to the ship and have contact with those meteorites that contain rewards. Meteorites are indistinguishable from each other in shape and color, so the only way to avoid harmful collisions is by resolving decimal metric equivalence. The equivalence to resolve appears in the top part of the screen showing a number and measure and posing the question "what is equivalent to…?". Reward meteorites are identified by the correct answer to such equivalence. This way, players review the content of the "Decimal Metric System" topic. Players have three additional lives to allow some errors or unwanted collisions, which will cause one life loss. The goal is to collect rewards by

colliding with correct meteorites. In this case, the pause button only stops the minigame in case players need more time to calculate the equivalence (e.g., on paper).

3.1.5 Function Memory

Function Memory belongs to the genre of memory games. Its mechanic consists of flipping a set of 10 cards, which appear face down. The cards can either contain functions (given by their formula) or their corresponding graphs (visually represented). Players need to match each formula with its correspondence graphical representation. If flipping a pair of cards that do not match each other, they go back to be face down. When correctly matching a formula with its representation, they will remain face up and slightly blurred to differentiate them from the cards still pending. This way, the minigame covers the "Graphs and Functions" topic. The goal is to match all 5 functions with their corresponding 5 graphs until all cards are face up and correctly matched. The pause button in this minigame solely stops the game, again for players to think about the representation of any shown formula or, vice versa, to try to think about the formula of any seen graphical representation.

3.1.6 Math Endless Runner

Math Endless Runner belongs to the endless runner genre. The objective of this minigame is to collect coins while dodging enemies by jumping them. In case of a collision with an enemy, the player would be presented with a basic mathematical operation, thus covering the "Integers" topic. In the case of correctly answering the question, the player is allowed to continue playing from the point where the collision happened. On the contrary, the player will start from the beginning again. The goal is to collect as many coins as possible. The pause button simply stops the endless run.

3.1.7 Minigames common elements

All minigames have the same structure: (1) a welcome screen that allows you to start the game, access an instruction screen explaining how to play the game, or go back to the main minigame selection menu; (2) the game itself that starts after clicking on that option in the welcome screen; and (3) an end screen that presents the summary of the information gathered from the game: time spent to complete, coins collected, pairs of cars flipped, etc.

All minigames allow you to pause the gameplay at any given time, so students have time to think about the question posed or take a break from playing. Some of these pauses provide additional help to complete the minigame, as detailed previously for each minigame. It is also possible during the games to directly exit the current gameplay and return to the minigame selection menu to change between minigames.

The game is open-source and freely available to play online[1] in a web browser. To better fit device characteristics, there are two different versions of the game: for PC, and tablets. Game controls are adapted correspondingly in each version of the game, so the game is prepared to take mouse and keyboard input in its PC version, while it considers touch-screen controls in its tablet version.

In addition to the game, a complete user guide was prepared for teachers and educators describing the minigames, their mechanics, and the mathematical content included in the game.

[1] https://nellyrl.itch.io/mathlien-land-mobile-v1

The purpose of this guide is to be a complementary tool to the game to support the use of the game in classes.

3.2 Evaluation questionnaires

As stated above, two different evaluation studies were carried out. The first one, with general population participants, is to early evaluate the usability of the game and find any potential bugs. The second one is a more specific evaluation study with participants from the target group of the game, to test their acceptance and opinion of the game. As such, two different after-game questionnaires were prepared for the evaluation studies. No personal information was gathered in the questionnaires, which were anonymously answered.

3.2.1 Questionnaire for the general population

The after-game questionnaire for the general population asked about:

1. Demographics: age, gender
2. Previous knowledge of the field: teaching expertise, knowledge of mathematic-based serious games for 12-14 years old
3. General game opinion
    a. Satisfaction with the videogame (scale)
    b. Usefulness to review mathematic concepts (scale)
    c. What did you like the most about the videogame in general?
    d. What did you like the least about the videogame in general?
4. Minigames' opinion, for each minigame, did they consider it:
    a. Fun (scale)
    b. Useful for content review (scale)
5. Usability
    a. How did you feel about the navigation between minigames? (scale)
    b. How did you feel learning how to play the minigames? (scale)
    c. Did English make playing the videogame harder? (scale)
    d. According to the device used, how positive was your experience? (scale)
6. Bug report: optional open question to report any possible bugs found
7. User guide: optional open questions to report the usefulness and improvements of the user guide, if used

All scale questions were to be answered using a 7-point Likert scale.

3.2.2 Questionnaire for end-users

The after-game questionnaire for end-users aimed to evaluate both the acceptance and opinion of the game. It included questions addressing:

1. Demographics: age, gender, and school grade
2. Minigames opinion, for each minigame:
    a. Did they find it fun (scale)
    b. Did they find the mathematical content included in it difficult (scale)
    c. Did they consider they learned with it (scale)
    d. What concept do they recall having reviewed in it
3. Usability
    a. How did you find navigating between minigames? (scale)
    b. How was it to understand how to play them? (scale)
    c. Did you have any issues with the language? (scale)
    d. According to the device used, how positive was your experience? (scale)
4. General game opinion
    a. What did you like most about the game?
    b. What would you change about the game?

c. Any additional comments

All scale questions were to be answered again using a 7-point Likert scale.

3.3 Participants

3.3.1 Participants in the general population survey

17 participants (35% men, and 65% women) completed the general evaluation questionnaire. No selection process was applied for this survey, which was distributed through several channels and authors' acquaintances. Participants had different profiles, with 25% stating to be teachers or educational professionals. These participants were given access to the game and the user guide, as well as the link to complete the evaluation questionnaire. They evaluated the game on their own, playing the game and completing the survey with no intervention from the authors.

3.3.2 Participants in the end-user's study

The evaluation with end-users was carried out in person in a school in Madrid (Spain) in May 2024. 40 students participated in the evaluation. Selection criteria were that all participants were within the target group of the game (i.e., students of the first cycle of secondary education (12-14 years old)). Two different sessions were carried out: the first one with a group of 25 students in the 1st year of secondary education and the second one with a group of 15 students in the 2nd year of secondary education. 39 students completed the post-test, and gender distribution was balanced (46% girls, 44% boys, 10% other/I rather not say).

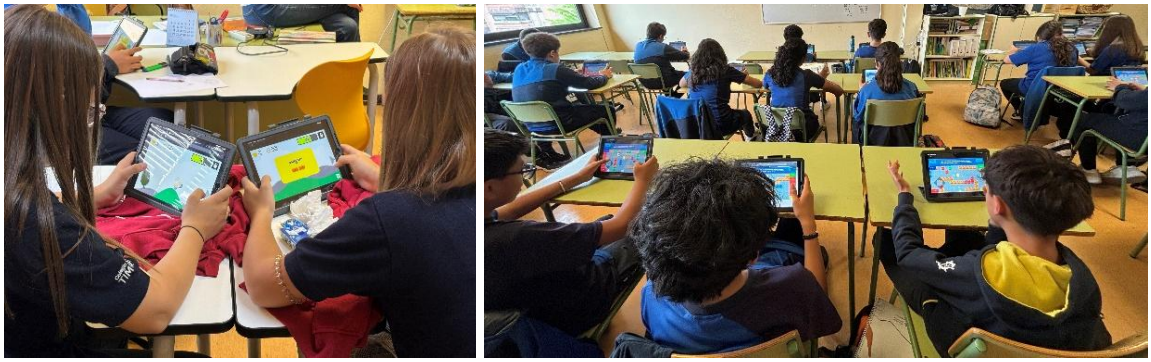

Figure 2. Students playing Mathlien Land.

Participants used the school iPads to play the game, accessing the version of Mathlien Land adapted to tablets and mobile devices through a QR displayed on the teachers' screen.

Figure 2 shows participants playing Mathlien Land during the evaluation study with end-users. Two of the authors were present during the sessions to introduce the activity and help participants if they had any issues while navigating the game but tried to keep their interventions to a minimum.

4. Results

This section presents the results obtained in both studies: the survey for general population participants (N=17), and the study with end-users (N=40), as described in the previous section.

4.1 Results of the general population survey

The questions included in the general population survey can be broadly classified into four blocks: opinion about the video game, usability, bugs reporting, and evaluation of the user's

manual, although the final objective of the survey was to evaluate the general usability of the tool. The responses to the question about previous knowledge of the field show that participants either did not know any mathematical game directed at 12-14 years (71% of participants) or mentioned alternative games (Brain Training, Duolingo Math) that either are not specific targeted at mathematics or cover a broader range of ages, particularly for younger players, as stated in the Background section.

The results obtained concerning the opinion of the video game overall (general game opinion questions) were very positive, with average ratings of 6.58 (SD = 0.77) out of 7 in terms of fun, and 6.29 (SD = 1.02) out of 7 in terms of educational usefulness. Similar data were obtained when asked about the minigames, with ratings of more than 5 out of 7 in terms of fun and usefulness, and "Math Endless Runner" obtained the highest scores in both aspects. Table 2 presents the results of the minigames opinion.

Table 2. Results of minigame opinion in the general population survey, providing mean evaluation scores for each category (and their standard deviations in parenthesis) for each minigame included in Mathlien Land

Minigame name	Fun	Useful for content review
Fraction Race	5.18 (1.65)	5.82 (1.69)
Labyrinth of Rule of Three	5.29 (1.74)	5.82 (1.62)
Dividing Hills	5.71 (1.87)	5.82 (1.64)
Decimal System Meteors	5.24 (1.66)	5.88 (1.29)
Function Memory	5.53 (1.88)	6.06 (1.29)
Math Endless Runner	5.88 (1.64)	6.47 (1.29)

In terms of usability, overall results were also positive. Particularly, ratings in terms of ease of navigation and understanding of the mechanics used in the minigames were also positive, with most respondents stating that it was very easy to navigate between minigames (71%) and easy or very easy to learn how to play the games (65%). Regarding the language used, 53% of participants had no problem with it, while some participants (17%) indicated that English was a problem for them. In terms of the experiences depending on the devices used, computers and cell phones were used for the most part, with an average rating of 6.36 (SD = 1.43) out of 7 and 4.8 (SD = 2.03) out of 7 respectively. These ratings indicated that the videogame worked correctly on these devices, although presenting small inconveniences in cell phones mainly caused by the smaller size of their screens.

The final open questions aimed to gather the reporting of possible bugs and the opinion of the user guide, if used. Participants reported only some minor bugs (12%), which included a bug in the "Labyrinth of Rule of Three" minigame and an unexpected music loop, both of which were consequently fixed. As for the user guide, only 7 out of the 17 participants reported using the user guide. They considered it very useful, with an average score of 6.86 (SD = 0.35) out of 7. Thus, despite the hiccups caused by using English and mobile devices, all participants were able to make satisfactory use of the tool, thus validating the video game in the first instance as a usable, entertaining, and educationally valuable tool.

4.2 Results of the study with end-users

The study with end-users aimed to verify the usefulness of the game and the opinion of it from participants of the target group that is meant to use the videogame (students in the first cycle of secondary education, i.e., 12 to 14 years old).

Table 3 presents the results of the evaluation study for each of the minigames for the 39 valid responses collected. The average score obtained in terms of fun was 5.23 (SD = 1.84) out of 7, which represents a positive evaluation of the entertainment provided by the minigames. In terms of difficulty, the average was 4.03 (SD = 1.85) out of 7, showing a not-too-high difficulty. These scores were similar for students in both courses. The average perceived learning score was 4.91 (SD = 1.90) out of 7, although their recall of the reviewed mathematical concepts was not too high.

Table 3. Results of evaluation study with end-users, providing mean evaluation scores for each category (and their standard deviations in parenthesis) for each minigame included in Mathlien Land

Minigame name	Fun	Difficulty	Perceived learning
Fraction Race	5.28 (1.68)	4.08 (1.91)	4.89 (1.88)
Labyrinth of Rule of Three	5.30 (1.79)	4.01 (1.85)	4.87 (1.96)
Dividing Hills	5.65 (1.72)	4.03 (1.63)	4.95 (1.91)
Decimal System Meteors	4.86 (2.06)	4.03 (1.89)	5.26 (1.85)
Function Memory	4.92 (1.99)	4.00 (1.76)	4.71 (1.85)
Math Endless Runner	5.35 (1.79)	4.00 (2.14)	4.76 (2.03)

Table 4. Results of evaluation study with end-users for each minigame included in Mathlien Land regarding recall of mathematical concepts

Minigame name	Correct recall	Incorrect	Did not recall
Fraction Race	36%	45%	19%
Labyrinth of Rule of Three	32%	42%	26%
Dividing Hills	25%	54%	21%
Decimal System Meteors	30%	42%	28%
Function Memory	41%	41%	18%
Math Endless Runner	46%	40%	14%

In terms of usability, results were also positive overall. Regarding the difficulty of navigation between minigames, scores were on average 3.10 (SD = 1.72) out of 7 (1 being easy, 7 difficult), with only 8% of users stating that it was in any way difficult, indicating that most users had no difficulties in switching between minigames, accessing help, and pausing the game. Similar results were obtained about the difficulty of the game mechanics used, with an average rating of 2.72 (SD = 1.60) out of 7 (1 being easy, 7 difficult) in this respect, and only 5% of users consider it in any way difficult, validating the ease of use of the minigames.

When asked if English was a problem for them, the average score was 3.69 (SD = 2.32) out of 7 (on a scale of *1 – the language was not a problem at all;* to *7 – the language was a huge problem*), with 26% of participants choosing values of 6 or 7, i.e., stating the language was a big problem for them.

As for the devices used, in this case, the study was carried out using the iPads available in the school, so all participants accessed the version of the game adapted to tablets. The results regarding the experience on these devices seem to have been positive, with an average score of 5.68 (SD = 1.47) out of 7, and 75% stating a somewhat positive experience.

Finally, the questionnaire included some open questions about game opinion. When asked to indicate what they would highlight positively about the videogame, some of the most repeated responses were the learning mechanics used, the subject matter and creativity involved, and the game's usability. Minigames mentioned were minigames 2, 3, and 5. In counterpoint, they were also asked to comment on the aspects of the video game that could be improved. 41% of participants did not state any improvements or that they would not change anything about the game. The rest, almost unanimously, mentioned the language as an aspect to be modified. Other aspects mentioned were the possible addition of different game genres and a decrease in the difficulty of the mathematical problems, particularly for the "Decimal System Meteors" minigame (which also had the lowest score in terms of fun, as shown in Table 3).

5. Discussion

5.1 Main Results

The study carried out to early evaluate Mathlien Land has shown a general acceptance of all six minigames included in the game, with some areas for improvement and extension. The opinion was mainly positive for all minigames in the end-user study, with all minigames having similar levels of difficulty for participants but some were considered to be more fun (e.g., Dividing Hills) than others (e.g., Decimal System Meteors) with a maximum of a 0.8 score difference. Navigation between minigames and game mechanics seems to be comprehensible for both the general population, but mainly for end-users. Some differences were found in device experience: tablets and PCs seemed to provide a better experience than cell phones. The screen size may be the cause as the game is designed to be played mainly in classrooms, where either PCs or tablets are expected to be available, to have a screen size sufficient to accommodate the game screen and the questions/options regarding the mathematical content. No relevant bugs or problems were detected in the general population survey, so the game was rapidly available for the end-user study with minimal changes. As for the negative results, one stands out: the language seemed to be the biggest barrier to understanding the game content and being able to play it successfully. Also, recall of minigames content was quite low overall.

5.2 Limitations

The study has several limitations. As for the general population survey, the lack of requirements for participants makes it difficult to extrapolate results, only giving a general idea of the game's usability. However, it was useful as a testing study to find bugs and verify that the game worked correctly. And, in addition, it helped to evaluate the user guide, which is indeed intended for teachers and educators, so it was not included as part of the end-user study. The end-user study was more useful as it targets participants meant to use the game. Limitations of this study are the size group, the fact that all participants are from the same school, which could potentially bias the results, and the lack of comparison of the tool with a control group. These limitations could be addressed in consequent evaluations of the game with larger and more diverse groups, while also using other measures for a control group. A final important limitation is the language barrier encountered by players: the fact that the game was designed in English was a higher issue than expected, so we will address this in subsequent studies by translating the game and/or testing it with native English speakers. Finally, while the current

minigames primarily target recognition and recall of mathematical vocabulary, this serves as a first step for deeper learning. However, the mechanics in the current version of some of the minigames could be more closely aligned with procedural or problem-solving aspects of mathematics. Future iterations will address this by integrating tasks that require applying procedures or reasoning processes (e.g., collecting or manipulating numerical items, applying proportional reasoning within the game environment), thereby linking gameplay more directly to mathematical learning. A subsequent evaluation phase will focus on measuring learning outcomes with these enhanced game mechanics.

5.3 Comparison with previous research

The overall positive acceptance of the serious game in our study aligns with earlier results for game-based learning strategies in schools, which have been found to increase student's interest and motivation [3]. The language barrier posed by the fact that the videogame was not in participants' first language was unexpected by researchers, maybe due to a lower English proficiency by students than anticipated. Conversely, serious games also pose an opportunity to strengthen students' English language abilities [35]. The present game may contribute to filling the gap of games for secondary education. Previous research literature reviews have highlighted the fact that most current mathematical-based learning games are targeted at primary education [27], [28].

5.4 Future research

Besides the limitations pointed out, which could be addressed in future research, there are other lines of work to continue to explore. A clear direct result of this study is the translation of the game to other languages to simplify its use for non-native English speakers. Additionally, we plan to include game learning analytics to collect and analyze relevant interactions of players in the game, which will provide more information about their learning process while playing. In the next iterations of the video game, once the design issues identified have been solved and the game improved, we plan to conduct an evaluation of players' learning with the game, which we plan to do in a pre-post study with, if feasible, a control group to compare the game with other learning materials.

6. Conclusions

This article presents Mathlien Land, a serious educational videogame to teach mathematical concepts to secondary education students. In particular, the game includes six independent minigames that cover the common mathematical concepts of the first cycle of secondary education (fractions, proportionality, divisibility, decimal metric system, graphs and functions, and integers). The minigames can be played independently but they all follow the same aesthetic and structure to be pieces of the overall video game.

After completing the initial version of the game, in this article, we have presented the results of the early evaluations carried out with the game: a usability test with the general population and a specific usability and acceptance evaluation with target users. Results have shown a positive perception of all minigames included in Mathlien Land, with also some opportunities for improvements, such as the translation of the game. After these initial evaluations, we plan to include the collection of analytics in the game to continue its evaluation with secondary students to contribute to their mathematical learning.

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Conflicts of interest

There are no conflicts of interest.

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