Mobile Application: A Serious Game Based in Gamification for Learning Mathematics in High School Students

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***Abstract*—In the present study, a serious game based on gamification techniques was developed to motivate the learning of mathematical topics seen in the last academic grade of Peruvian high schools. The proposed game was developed for mobile devices and uses a cloud-based web infrastructure. In addition, gamification techniques such as avatar, levels, progress indicators and rewards were used for its design. A total of 14 students participated in the experiment and qualitative data were collected through a questionnaire. The results showed that the selected gamification techniques were very effective in motivating learning, the serious game had a good user experience, and the students were satisfied with the learning experience of the game.**

I. Introduction

One of the most important subjects for students is mathematics, since it has a significant impact on their adaptation to daily life and allows them to achieve success in school [1]. In Peru, the education system is organized into three levels: initial, primary, and secondary education. For these levels, 31 competencies are established, in which 4 of which focus on the development of mathematical skills in the areas of arithmetic, algebra, statistics, probability, and geometry [2]. In order to learn about the progress of students in mathematics, tests are conducted from time to time. The 2019 Student Censal Evaluation [3] revealed that students in the second year of high school have increased their average score over the years. However, their score is still at the second level (beginning level) of the four levels designated according to the score obtained: pre-beginning, beginning level, level in progress, and satisfactory level. Likewise, according to the 2018 Programme for International Student Assessment (PISA) report, Peru is ranked 65 out of the 77 countries with the best average score in mathematics. Although the average score was higher with respect to the test conducted in 2015, these results are well below those of other countries.

Several studies recognize games as potential tools for learning mathematics. Prensky [4] proposes that digital game-based learning (DGBL) is an effective method that offers students an interactive and enjoyable environment. Based on this, studies using digital games for mathematics learning have shown positive results, such as the study by Sun, Ruokamo, Siklander, Li & Devlin [5], which sought to identify the effects on students' perceptions of learning with digital games through the use of scaffolding strategies by teachers during arithmetic learning sessions with the mobile game Wuzzit Trouble. The results showed that students had a greater interest in learning and were more encouraged to continue using the game. Furthermore, in the study by Kiili, Moeller & Ninaus [6], the effects of a digital game for mobile devices on the development of rational number concepts through training based on the number line are evaluated. The results indicated that students who played the game performed better than students who did not play the game.

While it is true that many studies use serious games as an educational tool for learning mathematics [7]–[9], most of these only focus on the primary school academic level and the mathematical area of arithmetic. In addition, studies aimed at the high school academic level do not focus on the practice of complex mathematics problems seen in books and exams [10]–[12]. For this reason, it is necessary to design and implement a serious game oriented to areas and topics of mathematics addressed in the last years of high school, to test the impact of serious games in this sector of students.

This study aims to present the development process of a game for mobile devices based on gamification techniques called *Mathyfight*, and to test the impact it has on the motivation for learning trigonometry in students in the last year of high school. For this purpose, an experiment was conducted with a group of fifth year high school students, in which a validation survey was conducted to assess the motivation generated by the game.

The remainder of the paper is organized as follows: Section 2 presents the state of the art of the research, which is divided into the phases of Planning, Development and Results and analysis; Section 3 presents the research proposal detailing the game design and validation process; Section 4 shows the results obtained, as well as the discussion based on them. Finally, Section 5 presents the relevant conclusions of the work, as well as future works.

II. Related Works

The elaboration of the state of the art of the present study was carried out by applying the systematic review of the literature following the approach of Wong, Mauricioa &

Rodriguez [13]. Three phases were used for its development, which are (1) Planning, (2) Development and (3) Results and analysis.

In the planning phase, the following research questions were formulated: What areas of mathematics have the different studies on mathematics learning covered? (RQ1), What academic level has the different studies on mathematics learning covered? (RQ2), What gamification techniques have been applied in mathematics learning? (RQ3) and What gamification techniques have been applied in learning? (RQ4).

The following keywords were defined for the search of articles: "math game", "serious game", "gamification" and "serious games on education", which were applied to the abstract, titles and keywords. The search was carried out in the scientific databases Scopus and Web of Science. The scientific articles found were evaluated and selected based on their compliance with the defined inclusion criteria. The inclusion criteria were: year of publication between 2018 and 2021, quartile Q1 or Q2 and published by a scientific journal.

In the development phase, the articles were searched in the specified databases, considering the fulfillment of the inclusion criteria. This was done with the objective of selecting the most relevant or main studies with respect to the research questions posed.

In the results phase, a total of 30 studies were obtained that met the previously defined inclusion criteria.

The articles acquired were analyzed using a taxonomy composed of 4 categories: Mathematical Area (RQ1), Academic Level (RQ2), Mathematical Gamification Techniques (RQ3) and General Gamification Techniques (RQ4), which are linked to the previously defined research questions (Table I).

TABLE I. ARTICLES ACCORDING TO THE PROPOSED TAXONOMY

Taxonomy	Reference	Quantity
Mathematical Area (RQ1)	[1], [5]–[11], [14]–[23]	18
Academic Level (RQ2)	[1], [5]–[12], [14]–[24]	20
Mathematical Gamification Techniques (RQ3)	[1], [5]–[7], [9]–[11], [14], [15], [17]–[24]	17
General Gamification Techniques (RQ4)	[25]–[34]	10

The "Mathematical Area" category is comprised of math subjects that were studied in the researched articles. A total of three mathematical areas were found in the literature: arithmetic, probability, and geometry (Table II). As seen in the table, there is a lack of research on the effects of gamification in various areas and topics of mathematics. For example, of the 18 articles found only 1 focuses on the area of probability and 2 on geometry. Therefore, the question remains as to whether serious games could be useful for motivating the learning of other more complex mathematical areas, such as trigonometry, which is the main reason why that area was chosen in the present study.

TABLE II. ARTICLES BY MATHEMATICAL AREA

Area	Reference	Quantity
Arithmetic	[1], [5]–[9], [14], [15], [17]–[23]	15
Probability	[10]	1
Geometry	[11], [16]	2

The "Academic Area" category is comprised of the academic levels of the participants during the validation process in the researched articles. Three academic levels were found: primary, high school, and preschool (Table III). As seen in the table, most of the literature focuses on the primary academic level, while very few articles focus on preschool and high school. More importantly, the highest academic grade explored in the articles was ninth grade in a high school on the United States of America [11], which means that there is a lack of research on the motivation for serious games in the later grades of high school, such as tenth, eleventh, and twelfth grade. This is important because students are preparing to apply to a university, and it is interesting to know if serious games are still effective in motivating them to learn during this stage of schooling.

TABLE III. ARTICLES BY ACADEMIC LEVEL

Academic Level	Reference	Quantity
Primary	[5]–[9], [14]–[19], [21]–[24]	15
High school	[10]–[12], [20]	4
Preschool	[1]	1

The "Mathematical Gamification Techniques" category is comprised by gamification techniques applied in videogames used by research articles, where the learning subject used in the game was related to math. The following gamification techniques were identified: levels, feedback, rewards, progress indicators, points, medals, narratives, leaderboards, and avatar (Table IV). As seen in the table, there are many gamification techniques used in serious games that focus on learning mathematics. The first technique chosen for the serious game developed was levels. Thanks to the large number of games that implemented this technique, it was identified that the main ways to use levels in serious games are to challenge the player to solve progressively more difficult math problems in each level or make them solve more problems to win each level. On one hand, students who do not excel in mathematics can practice at their own pace and improve little by little. On the other hand, players motivated to win would be practicing more problems per level, which is very beneficial for their learning. These two factors contributed greatly to the choosing of this technique in the developed serious game. Alongside levels, most serious games included compensation if players won them. This was represented in the form of points or rewards. Therefore, in the developed game we chose to include rewards to the players after winning a level. Progress indicators and avatar techniques were also chosen to analyze their support for learning motivation, since very few serious games had used them. For example, progress indicators can make participants feel proud of their mastery [22] and avatars help the player immerse themselves inside the game, as seen in [15], [24].

TABLE IV. ARTICLES BY MATHEMATICAL GAMIFICATION TECHNIQUES

Technique	Reference	Quantity
Levels	[1], [5]–[7], [9], [11], [12], [17], [18], [20], [21], [23]	12
Feedback	[6], [11], [17], [19]–[21], [23]	7
Rewards	[5]–[7], [17], [22]	5
Progress indicators	[22]	1
Points	[5]–[7], [9], [10], [12], [13], [18], [19], [24]	10
Medals	[14], [20]	2
Narratives	[19], [24]	2
Leaderboards	[19]	1
Avatar	[15], [24]	2

Finally, the category "General Gamification Techniques" is comprised by gamification techniques applied in videogames used by research articles, where the learning subject used in the game was not related to math. A total of eight techniques were identified: levels, feedback, rewards, medals, leaderboards, points, narratives, and avatar (Table V). This research was done with focus of identified other potential gamification techniques that could be used in the developed game. No new gamification techniques were found, but it was identified that there was also a lack of research on avatars and progress indicators. It was also identified that in these other learning subjects' levels were the most used technique and that they were used alongside with points and rewards.

TABLE V. ARTICLES BY GENERAL GAMIFICATION TECHNIQUES

Technique	Reference	Quantity
Levels	[25]–[28], [31], [34]	6
Feedback	[25], [28], [30]–[33]	6
Rewards	[27], [28]	2
Medals	[27]	1
Leaderboards	[27]	1
Points	[28], [30], [32]	3
Narratives	[29], [31], [34]	3
Avatar	[34]	1

III. MATERIALS AND METHODS

The developed serious game is composed of a mobile application and a web infrastructure (Fig. 1). In addition, since the main goal of the game is to motivate students to learn mathematics, gamification techniques were implemented in the serious game. An experiment was also conducted with students to evaluate the motivation generated by the game, which was measured through a qualitative survey.

A. Elements of the game

The serious game developed is composed of 5 main elements: level and experience of the avatar, attributes, calculated damage in a battle, objects, and the timer of mathematical problems.

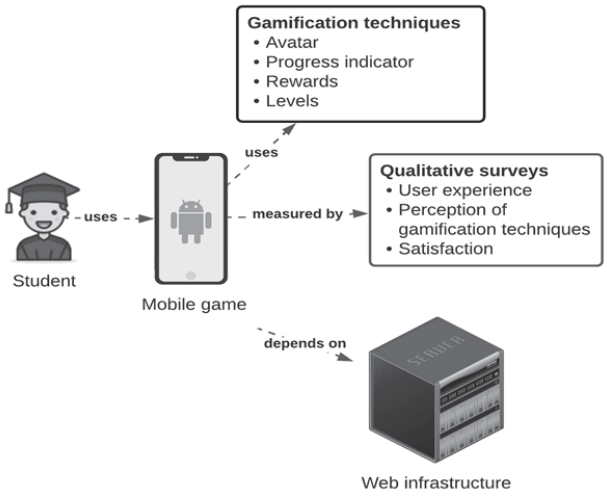

Fig. 1. Serious game design

1) Avatar level and experience: In the game, each player has an avatar that has an assigned level and needs to gain experience to level up. The starting level is 1 and the maximum level is 50. The total experience required to level up when the avatar is at a given level is defined by Eq. (1).

$$ERNL = Level \times 100 \quad (1)$$

where *ERNL* represents the experience required for the next level.

2) Attributes: Players' avatar and enemies in the game have three attributes that define their performance in a battle.

- Attack: It represents the attack that a player or enemy has. For the player, its value ranges from 1 to 50. For the enemy, its value varies between 3 and 52.
- Defense: It represents the defense that a player or enemy has. For the player, its value varies between 1 and 50. For the enemy, its value varies between 2 and 213.
- Health: It represents the health that a player or enemy has. For the player, its value varies between 3 and 150. For the enemy, its value varies between 3 and 212.

In addition, each time an avatar levels up it gains 1 attack and 3 defense and health.

3) Damage: The attack is related to the damage that an enemy or avatar can inflict on an opponent. To calculate the damage an avatar can inflict on an enemy, the attack modifier must be taken into consideration. This modifier is set after a player starts a battle and selects the difficulty of the mathematical problem to be solved. If the player selects easy, intermediate, or advanced difficulty, the value of the modifier will be 1.0, 1.5 and 2.0, respectively.

This modifier is used for the calculation of the damage that the avatar inflicts on the enemy, which is defined with Eq. (2). The damage inflicted can reduce the defense or health of the opponent. For the defense to decrease in a battle, the defense must be greater than 0 and damage must be received. The

calculation of the remaining defense when receiving an attack is defined by Eq. (3). For the health to decrease, the damage to be received must be greater than the remaining defense during the battle. The calculation of the remaining health when receiving an attack is defined by Eq. (4).

$$Damage = Attack \times AttackModifier \quad (2)$$

$$RemainingDefense = Defense - OpponentDamage \quad (3)$$

$$RemainingHealth = Health - (OpponentDamage - Defense) \quad (4)$$

4) Objects: Objects are divided into six types: helmet, breastplate, pants, boots, weapon, and shield. Helmets, breastplates, pants, boots, and shields have the defense attribute and weapons have the attack attribute. These serve to increase the avatar's defense or attack when equipped. The total defense and attack of the avatar is defined by Eq. (5) and Eq. (6) respectively.

$$TotalDefense = Defense + EquippedObjectsDefense \quad (5)$$

$$TotalAttack = Attack + EquippedObjectsAttack \quad (6)$$

The objects are divided into ten categories, with the first category having the lowest attribute values and the tenth category having the highest values. For armor and shields, the increase in attribute value is 1 unit per category and for weapons it is 9 units per category (Table VI).

Objects also have a purchase price in game gold. The purchase price depends on the category (Table VII).

TABLE VI. ATTRIBUTE VALUES FOR EACH TYPE OF OBJECT AND CATEGORY

Taxonomy	Category 1		…	Category 10	
	Defense	Attack	…	Defense	Attack
Helmet	2	-	…	11	-
Breastplate	4	-	…	13	-
Pants	3	-	…	12	-
Boots	1	-	…	10	-
Weapon	-	9	…	-	92
Shield	3	-	…	12	-

TABLE VII. PURCHASE PRICE OF OBJECTS

Category	1	2	3	4	5	6	7	8	9	10
Purchase price	2	3	5	7	9	13	15	17	21	23

5) Mathematical problem timer: For a player to win a battle he must solve mathematical problems under a time interval that depends on the difficulty of the problem. If the player selects the easy, intermediate, or advanced difficulty, the time interval will be 3, 5 and 7 minutes, respectively. Also, if the player solves the problem within the set time limit, then he attacks the enemy. Otherwise, he is attacked by the enemy.

B. Gamification techniques

Gamification techniques are commonly used in higher education to increase motivation and entertainment in a learning activity [35]. Therefore, four gamification techniques identified by Alomari, Al-Samarraie & Yousef [35] were chosen to increase players' motivation to learn: avatar, levels, progress indicator and rewards.

1) Avatar: Avatars are an entity through which the player can interact in the game. Some researchers suggest that using avatars in educational games increases students' motivation to learn [36]. Therefore, in the present game, all players have an avatar. In addition, players can customize their avatar to their liking to better represent them in the game. The customization options enable players to change the objects they have equipped to improve their performance in battles, and they can also change the appearance of their avatar.

2) Progress indicator: Previous studies [37], [38] have shown that a progress indicator such as a progress bar can enhance students' entertainment and motivation, by allowing them to identify their progress throughout a learning session. Therefore, in the present game, progress bars are included for four approaches with their respective indicators (Table VIII).

TABLE VIII. APPROACHES AND GAME PROGRESS INDICATORS

Approaches	Indicators
By battles	Number of battles fought, won, and lost
By levels of difficulty	Number of math problems attempted, solved, and failed.
By mathematical areas	Number of math problems attempted, solved, and failed.
By mathematics topics	Number of math problems attempted, solved, and failed.

3) Rewards: Rewards can help in motivating students to learn [37]. Therefore, in the present game, when a player defeats an enemy in battle, he gets two rewards: gold and experience. The gold is used to buy new objects to strengthen the player's avatar and experience is used to increase the avatar's level.

4) Levels: Levels are a way to measure a player's progress in different stages, based on a difference in difficulty. Each level is unlocked as soon as the player wins the previous level to the one he wishes to unlock. Several studies indicate that the use of levels can improve students' motivation while learning complex topics [35], [39]–[41]. Therefore, in the present game, each mathematics topic has 11 levels. Moreover, the difficulty of the battles in each level increases incrementally. The first level is the easiest to win and the last is the most difficult. Each level of each topic has a unique enemy and the enemy's health, attack and defense depend on the level. The gold and experience awarded to the player also depend on the level (Table IX).

TABLE IX. DISTRIBUTION OF TOPIC LEVELS

Level	Enemy			Rewards	
	Health	Attack	Defense	Gold	Experience
0	3	3	2	2	25
1	22	7	21	6	125
2	44	12	41	10	225
3	64	17	64	14	325
4	85	22	85	18	425
5	108	27	105	26	525
6	128	32	127	30	625
7	149	37	149	34	725
8	170	42	170	38	825
9	192	47	191	42	925
10	212	52	213	46	1025

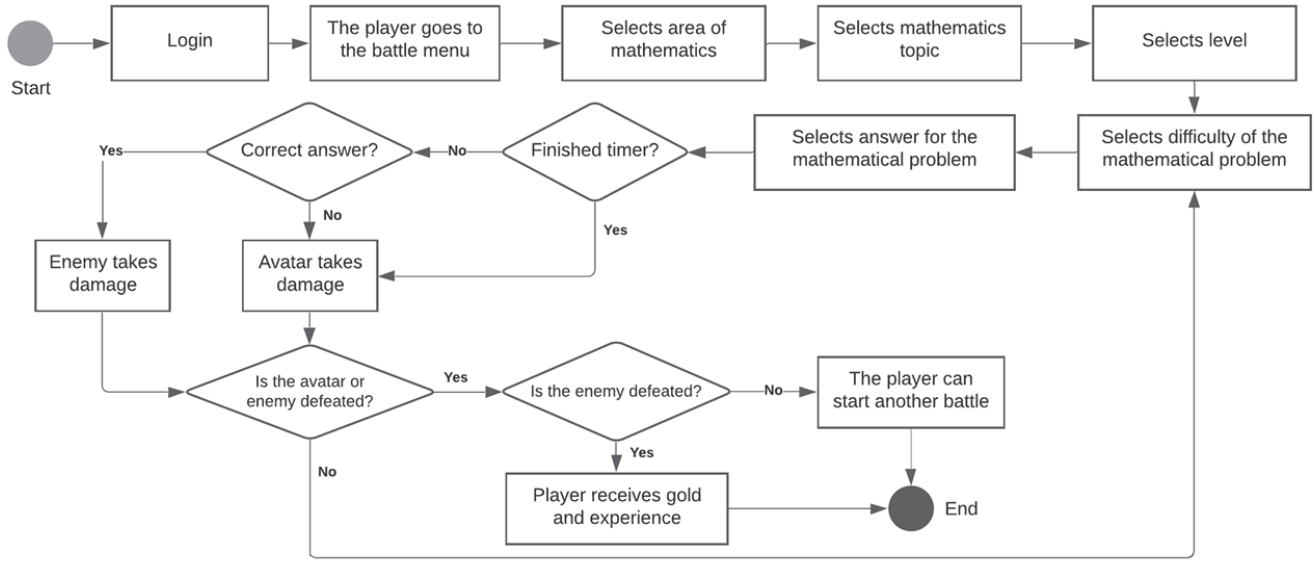

Fig. 2. Game procedure

C. Game procedure

The serious game has features that allow the player to practice his mathematical knowledge. One of the most important is the *battle*, which allows the player to fight against an enemy and defeat it by solving mathematical problems. The battle procedure is shown in Fig. 2.

This starts with the ***login***, here the player must enter his credentials to access the game.

Then, the player must go to the ***battle menu***, where he must ***select the area of mathematics*** he wishes to reinforce. It should be noted that the scope of the game only covers the areas of trigonometry. Subsequently, the player must ***select a topic from the area***.

The last step before starting the battle is the ***selection of the level of the mathematics topic***. Then the battle will start, in which the player's avatar and the enemy will be displayed. To proceed with the battle, the player must ***select the difficulty of the mathematical problem*** to be solved. When this action is performed, a mathematical problem will be displayed according to the area, topic and difficulty selected, which must be solved in a given time interval according to the selected difficulty. Multiple-choice questions were chosen because they are a simple and objective way to evaluate student responses. In addition, they are adaptable to various mathematical areas and topics.

If the player ***selects the correct answer*** to the problem, then he is considered to have won the turn, so the ***enemy takes damage***. Otherwise, if the player incorrectly solves the problem or runs out of time on the timer, he is considered to have lost the turn and the ***avatar takes damage***.

If the player's or enemy's health reaches zero, then the battle is over. On the one hand, if the player lost all his life, then the player is considered to have lost the battle and will receive no rewards. On the other hand, if the enemy lost all his life, then the player is considered to have won the battle. Therefore, he will ***receive rewards*** such as *gold* and *experience*.

Finally, regardless of the result obtained, the player will be able to ***start a new battle*** with a different area, topic, or level.

D. Game architecture

The architecture of the game is represented in Fig. 3, where it can be seen that the student uses the mobile application to start the game. The application communicates with the web infrastructure, for this it first communicates with a RESTful API, to obtain the necessary data and process the business logic. This in turn communicates with a MySQL database and a file server to obtain and persist data and images, respectively. The web infrastructure is deployed in the Microsoft Azure cloud service.

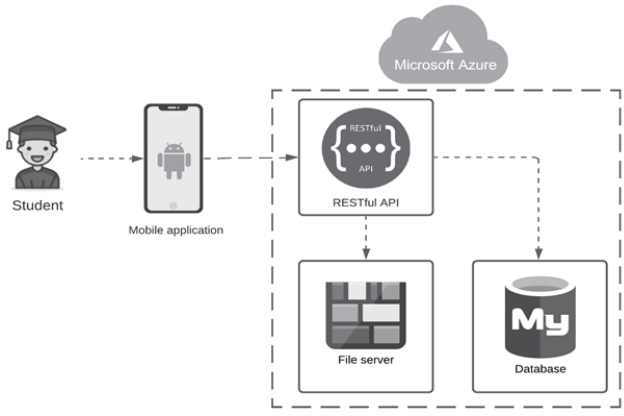

Fig. 3. Game procedure

1) Mobile application: The proposed serious game is available to players through a mobile application for Android devices. The Android operating system was chosen because it covers most of the market, which allows the proposed serious

game to be available on most mobile devices. The game is developed with the open-source framework Flutter.

The application is divided into 5 modules: authentication, battle, store, avatar, and profile. The first module is responsible for the authentication of the player's account, among its responsibilities are login and registration.

The battle-related interfaces are shown in Fig. 4a and Fig. 4b. It should be noted that the utility of a battle is to allow players to reinforce their mathematical knowledge by solving problems to defeat an enemy.

The beginning of the battle is shown in Fig. 4a, where the attributes of the avatar and the enemy, and the difficulty levels for the mathematical problem to be solved (easy, intermediate, advanced) are shown.

After a difficulty is selected, the problem-solving interface is displayed (Fig. 4b) showing a description of the problem, an image, the possible answers that the player can select and the attributes of the avatar and the enemy.

The store interface is shown in Fig. 4c. The store allows the player to buy new and sell existing objects. These objects are used to improve the attack and defense attributes of the avatar.

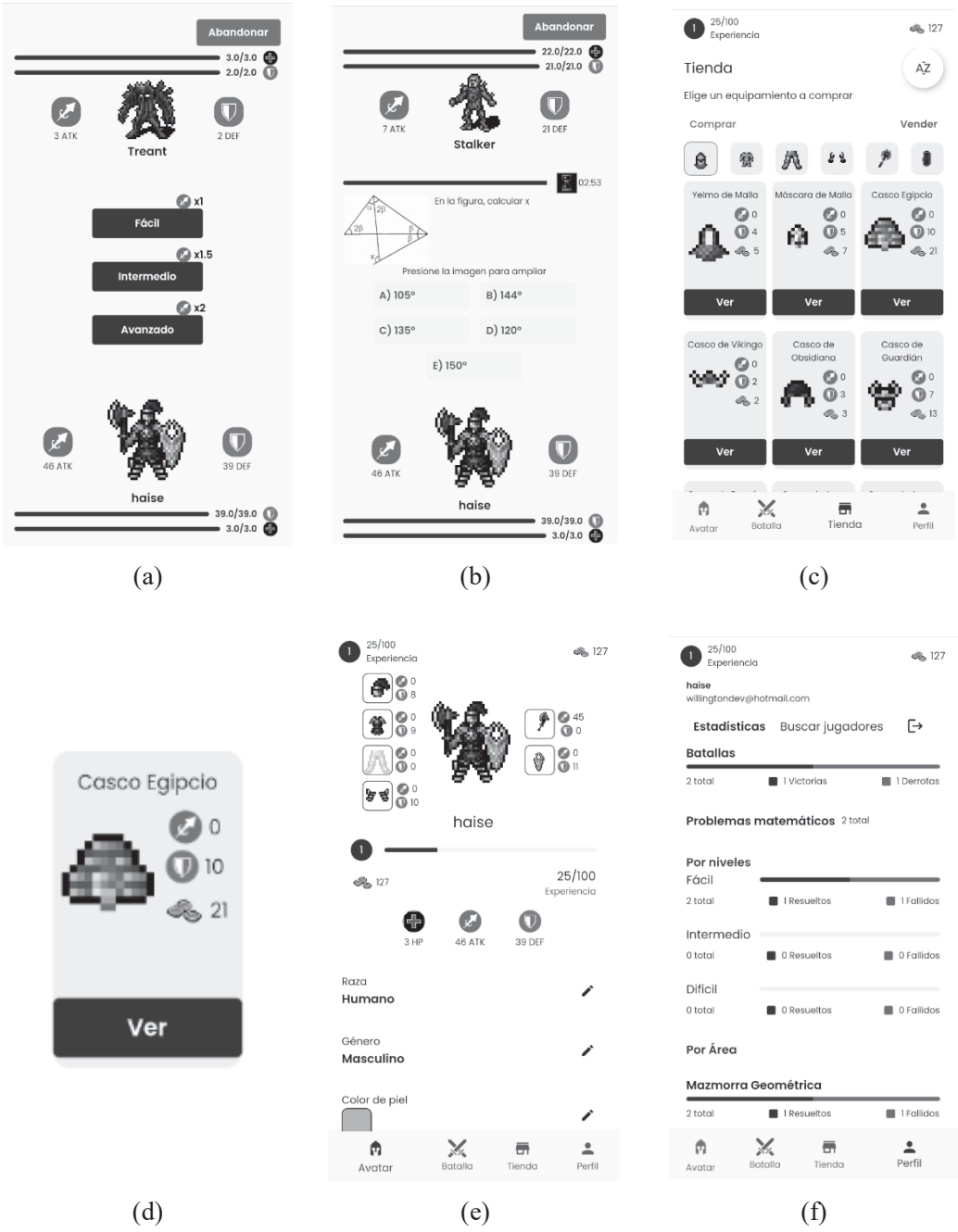

Fig. 4. Game interface

For example, in Fig. 4d a "helmet" type object is shown with its attributes and its purchase value.

Fig. 4e shows the avatar interface, in this screen the player can customize his avatar according to his preferences.

Finally, Fig. 4f shows the profile interface, in this screen the player can view his statistics to track his progress in the game. It shows several statistics. (1) the total number of battles, the number of battles won and lost. (2) the number of math problems attempted, solved, and failed (by difficulty level, by math area, by math topic).

2) Web infrastructure: As mentioned above, the web infrastructure is divided into 3 components (Fig. 3). The first component of the web infrastructure is a RESTful API that is deployed in the Azure App Service. The NestJS web application framework with the TypeScript programming language was used for its development. The responsibility of the component is to manage access and modification of data stored on the file server and in the database. The second component is a file server that is deployed on the Azure Blob Storage service. The responsibility of the component is to store the game images. Finally, the third component is a relational database that uses the MySQL relational database management system and is deployed on the Azure Database for MySQL service. The responsibility of the component is to store the game data.

3) Validation process: To measure the effectiveness of the serious game developed, an experiment was conducted with a sample of 14 students from a fifth-grade classroom of high school in Lima, Peru.

Fig. 5 shows the process of the experiment. The experiment began with an hour-long presentation of the game. During this presentation, all the features of the game were shown to the students. Also, any doubts they had were answered. Then a qualitative questionnaire was given to the students with a duration of 10 minutes. This questionnaire was divided into 3 sections. The first section evaluated the user experience. Seven questions with a 5-point Likert scale were used and the content was adapted from the User Experience Questionnaire [42]. The second section was separated by 4 questions that assessed the motivation perceived by the gamification techniques used. The last section assessed perceived satisfaction with learning with games. Three questions were asked with a 5-point Likert scale and the content was adapted from the satisfaction questionnaire of Cai [10]. Additionally, participants were asked an open-ended question to find out which new feature they would like to see in the game.

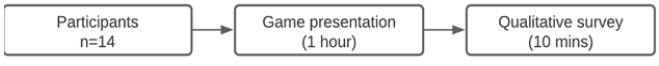

Fig. 5. Experiment process

IV. Results and Discussion

This section shows the results obtained after collecting the students' responses from the user experience, perception of gamification techniques and perceived satisfaction sections of the questionnaire.

Fig. 6 shows the results of the "user experience" section, with respect to the proposed game *MathyFight*. The results show that more than 60% of the participants agreed or strongly agreed that the game is creative, easy to learn, supports them in their learning, interesting, novel, attractive and innovative.

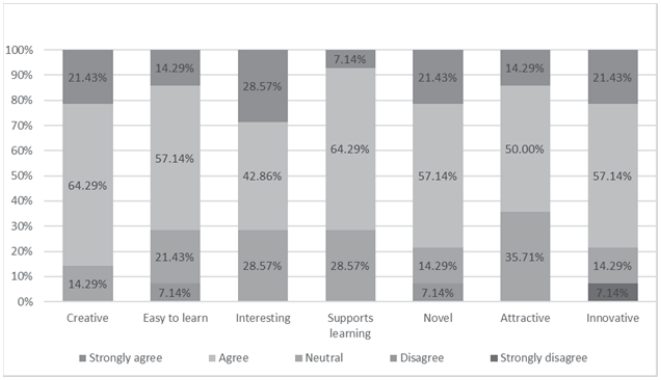

Fig. 6. User experience results

Fig. 7 shows the results of the questions evaluating the gamification techniques applied. The results indicate that more than 64% of the participants agreed or strongly agreed that the use of levels, rewards and progress indicators would motivate them to continue playing.

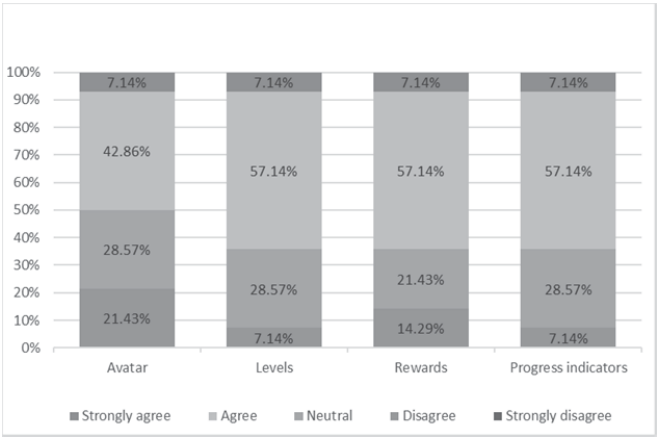

Fig. 7. Perception of gamification techniques results

Finally, Fig. 8 shows the results of the "satisfaction" section. The results indicate that more than 90% agreed that other courses use serious games for learning. In addition, it is noted that 80% agreed to recommend the use of serious games to their friends and acquaintances.

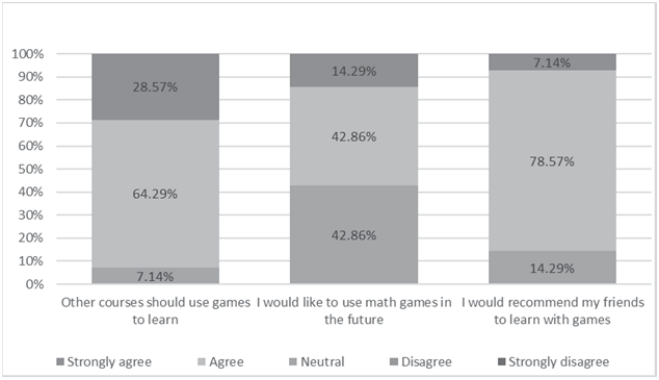

Fig. 8. Perceived satisfaction results

Finally, Fig. 9 shows the results of the last question. The results show that the most requested feature to be added to the game is the multiplayer mode. This is an indicator that competition between players would increase the motivation of the game.

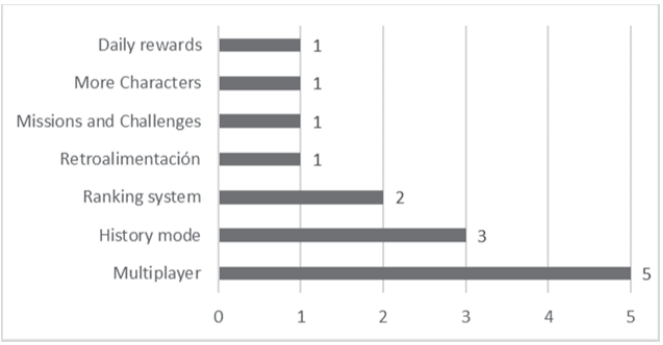

Fig. 9. New feature results

In general, the results of the experiment show an improvement in the motivation of the students when applying the selected gamification techniques, these results are consistent with the results obtained in [30], in which a microworld based role-playing game was used to significantly improve students' motivation to learn mathematics.

V. Conclusions and Recommendations

In this study, a serious game called *MathyFight* was developed for learning the mathematical area of trigonometry in students of the last academic grade of high school. For the game design, 4 gamification techniques (avatar, levels, rewards, progress indicator) seen in the literature were used to increase players' motivation. An experiment was then conducted with 14 students in the fifth grade of high school in an educational institution in Lima in order to evaluate the motivation generated by the game.

The results of the validation showed that with respect to the "user experience", more than 60% of the participants agreed with 7 aspects of the game. Regarding the "gamification techniques" applied, there was a positive reception with respect to motivation (60%). And, with respect to "perceived satisfaction", more than 50% of the sample perceived a high degree of satisfaction with the use and recommendation of games for learning.

The gamification techniques used in *MathyFight* obtained positive results. For this reason, it is recommended that different gamification techniques be explored for future work to determine their impact. Also, it is recommended to add social aspects such as a multiplayer mode to increase the persuasiveness and attractiveness of the game. This is also supported by the opinions of students since it was the most requested feature by the students. In addition, it is recommended that larger samples be obtained in future work to obtain more accurate results.

Finally, although quantitative tests were not implemented during the validation process to see if students improved their academic performance after the playing the game, the experiment confirmed that the first impressions of the game were very positive and that students were open to the idea that a serious game could motivate them in learning trigonometry. This is important because serious games need to be attractive in order to retain players in the long term. However, these types of tests are still an important aspect to investigate, and it is recommended that they are evaluated for the academic level researched in the present study and the area of trigonometry.

VI. Acknowledgment

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