Development of Educational Video Game on Algebra as a Teaching Learning Tool

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Abstract: - In this paper the design, development and implementation of an educational video game about mathematics is presented, in specific algebra for high school students, that serves as a teaching learning tool. The game is in third person and the character has freedom of movement; that is, it is in three dimensions. All the steps for the creation of the videogame are described in detail, such as: gameplay, storyboard, production of characters, objects and scenarios, audio design, programming, testing and Beta version. The purpose is to persuade students to both perform an activity they like, such as playing video games, and strengthen their math skills in the process. To demonstrate the efficiency of the video game, 4 high school groups that were taking the subject of algebra were asked to play it. As result, 97 of 118 students completed one level on time. With this investigation, new learning models that complement the already traditional ones are developed, emphasizing that they are part of the information and communication technologies that are liked by most students.

Key-Words: - Algebra, Computer video game, Information and Communication Technologies, Improving classroom teaching, Interactive learning environments, Media in education, Teaching/learning strategies.

1 Introduction

Today, the use of new technologies has reached all areas of daily life. Information and Communication Technology (ICT) is a force that has change many aspects of the way people live. In schools, their employment has gradually grown, although in many places they are not yet a fundamental part of learning. There have been many factors impeding the wholesale uptake of ICT in education across all sectors, including a lack of support, training and motivation to adopt ICT as teaching tools [1]. Hence, the need to create innovative things to improve educational tools. ICT applications provide many options and the institutions are now creating competitive edges for themselves through the choices they are offering for students. These choices extend from when students can choose to learn to where they learn [2]. ICT competence is also closely related to the development of such skills as creativity, logical reasoning, critical thinking and problem solving, decision making, networking, etc. [3]. The presence of ICT has led to major changes in the traditional teaching methods, incorporating new methods that optimize training. Virtually, any ICT can become a teaching media if it meets or helps meeting learning objectives.

In schools, students perform tasks and practices on computers as part of their learning process. However, at home they prefer to play video games, which is not very well seen by their parents and teachers. Video games are closely linked to new technologies that are strongly taking children and adolescents, so it is essential to develop video games that attract the attention of students and at the same time provide them with school knowledge. The commercial popularity of video games is beginning to transpose to the classroom. The use of these gaming technologies requires users to manipulate virtual objects using electronic tools and develop an understanding of the complex systems being modeled [4]. Although the reality is that the infrastructure of schools is far from favoring the systematic use of these media. The real and daily are traditional resources, such as written texts, blackboard and projector [5]. The repetition of these learning techniques causes students to become distracted and not catch the message, even losing interest in the subject. For this reason, new learning techniques must be created to draw the attention of the students according to the degree they are taking and mainly the activities they like to do.

In some areas, computer and video games have been ignored by educators. When they have

discussed games, they have focused on the social consequences of game play, ignoring important educational potentials of gaming. Contemporary developments in gaming, particularly interactive stories, digital authoring tools, and collaborative worlds, suggest powerful new opportunities for educational media [6]. The clearest effect of the educational potential of video games is through the acquisition of digital skills. Most children start in the digital world through electronic games and, in this way, acquire competences of digital literacy [7]. The purpose of this work is not to make an argument in favor of video games, but to enter into their knowledge, since the development of this technology opens multiple possibilities in the educational field. In recent years, the use of video games has been increasing, whether by means of a console, a cell phone or an electronic tablet, reaching practically the entire society, especially adolescents. Hence the importance of understanding how valuable and important the proposal is to introduce videogames educationally [8]. Recently, different institutions and companies have tried to make educational video games look a little more like commercial video games, this to make them more fun and attractive for students.

The present research aims to design, develop and implement a three-dimensional educational video game that helps the teaching learning process. To limit the project, the high school is considered as grade level. Basic school algebra topics are taken as the area of study. This entails making a good story and graphics for the video game, but at the same time designing quality educational content. With this, new models of learning are developed, emphasizing that they are liked by most teenagers.

2 Video games in education

The advancement of technology has produced society to increasingly entering the digital era of knowledge and information. The education sector is not far behind and uses technology to make the teaching process faster and more agile. From the use of interactive whiteboards, educational videos, virtual platforms, apps for mobile devices and more, the use of ICT is increasing. When the words “fun” and “interactive” are mentioned in the same sentence, the new generation would always think of video games. Video games are highly interactive virtual environments where users spend hours of playing every day without any complaints or regrets [9]. There are several experiences based on educational video games made at different levels, including highlights:

- Dragon Box: In this game, children must arrange icons in a certain order to unlock the dragonbox. As they continue to play, the icons are slowly replaced with numbers and variables, showing that they’ve been solving math problems all along [10].
- Hakitzu: It proposes a tournament of robots fight in which it will be necessary to learn to program in order to win. Through increasingly sophisticated scripts, it is possible to be proclaimed champion of the tournament, an entertaining and motivating way to learn to program. [11].
- Minicraft: It is a virtual sandbox where the child can create and destroy new constructions using blocks. Minecraft encourages the child to interact and learn from their surroundings. [10].
- Naraba World: This video game proposes a trip to Naraba, a world of fantasy, in which the user must explore to solve the mysteries and riddles putting on its knowledge into practice [11].

The most important uses of video games in classrooms are those that designed and developed, from the beginning, to have an educational component. In these cases, the game is designed to teach a specific educational content and is introduced to encourage student motivation. Educational video games allow complementing, and sometimes replacing, resources of a more traditional character.

It is important to emphasize how video games influence the learning processes of children and teenagers, as well as their effects on the educational process in general [12]. The use of educational video games is an attractive and motivating element for the school population, since learning is implicit through hidden concepts in the challenges and activities of the video game itself, as well as the application of collaborative learning techniques that allow students to develop their social skills as they learn and gain more effective learning. Several game developers and educators have already fathomed the opportunity to produce such games that would elevate the level of education for different fields. Educational games for several fields including algebra, geology and biology have been developed and tested on many students yielding up to 40% learning increase over regular classes [13].

For this reason, ICT based learning should be considered within the classrooms, through fun individual and group tasks, acquiring curricular competences, developing a research thinking, socializing the lived experiences, i.e. experimenting

with different models, methodologies, tools and educational experiences according to the possibilities offered by video games mainly [14].

3 Design and development of video game

To create a video game, the most important thing is to have clear concepts from the beginning and generate a great idea of what to do. The idea is to create an educational video game about various math topics for high school students that can be played on a computer, specifically the area of algebra. Algebra is chosen because it is the first branch of mathematics that students learn in high school, so it is the basis of the other branches. If students achieve proper learning in this area, they will have more confidence to move on with math. In addition, the teenagers who attend the high school are in the age in which they play more video games. To achieve this, the six main algebra topics were selected, assigning each one a level of play. To make the video game more interesting, each level takes place in a city known worldwide. It generates a cultural contribution that is liked by teenagers, because through the game they can know a place in another part of the world. The relation of the algebra topics and places by each level are:

- Level 1: Algebra basics – Egyptian pyramids, Egypt.
- Level 2: Algebraic operations – Paris, France.
- Level 3: Special products and factoring – Moscow, Russia.
- Level 4: First degree equations – Tokyo, Japan.
- Level 5: System of equations – New York, USA.
- Level 6: Second degree equations – Teotihuacan pyramids, Mexico.

After defining the mathematical content, another important point is the character of the video game. For its creation, people who have had contributions to mathematics are considered; Hypatia of Alexandria excels for being the first known woman mathematician. To produce the character, activities such as modeling, UV mapping, rigging, animation, state machine and rendering are contemplated, using specialized software like Maya, ZBrush, Photoshop and Blender. In Maya, the character is modeled taking care of the number of polygons used because it can produce a very robust file. Also, in Maya the UV mapping is obtained for placing the textures correctly. Then it passed to ZBrush for texturing. The textures used are created in Photoshop. In Blender and Maya, the joints are put to the character to produce movement and thus, to become an animated and interactive character. Finally, Rendering is done to make more real the character. Figure 1 shows the character production process.

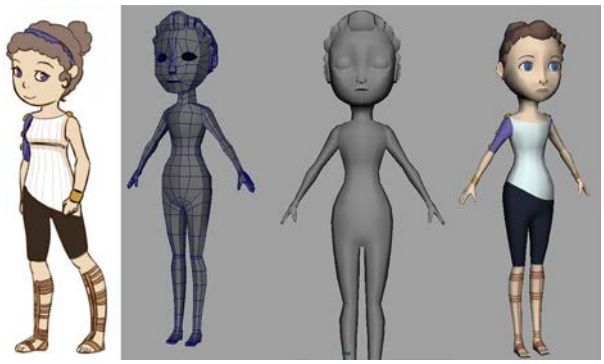

Figure 1. Production of the animated character.

Modeling consists of shaping individual objects, based on a reference image. The UV mapping represents the coordinates of the texture in the model, which in 3D view coincide with the position of the vertex but have an independent movement in its unfolded form. Texturing is made to increase the detail and realism of the models by incorporating textures, it is an image that is placed on the faces of the polygon. Rigging is a process in which a skeleton is built with its bone chains to function as needed. This can be a very simple process or a too complicated job, not only because there are many strings but also because these strings can carry many implicit constraints. The animation consists of creating images in movement by means of a computer. The state machine is a program structure which purpose is to determine the behavior of something based on the state in which it is. For each state, consequently, a behavior will occur. Rendering is the process of generating an image from a 3D model (or scene file) by means of computer programs. A scene file contains objects in a strictly defined language or data structure; it would contain geometry, viewpoint, texture, lighting and shading information as a description of the virtual scene. This process usually takes time to perform.

Also, the gameplay or history of the video game is determined, since it is the main thing to capture the attention of the students. The approach is as follows: the character (Hypatia) prepares to present her final math test; however, she realizes that she does not have the necessary material to do it, such as pencil, rubber, notebook, calculator, ruler, etc. This is presented in an Intro of about 20 seconds. To obtain these school supplies, the character must go

through the six levels and in each one of them, solve the mathematical exercises. For each correct answer, it is possible to obtain some school supplies. As it is a game in three dimensions, the character can move freely around the stage and look for the location of the different exercises. At each level, there is the possibility to choose clues as an aid to solve the exercises, as well as prizes to improve the final score. Obviously, there is a time limit to solve each exercise and to finish each level. If the exercises are solved quickly and few mistakes are made, the score obtained will be higher. In each level, there are between five and ten exercises according to the degree of difficulty of the topic and are randomly taken from a box of 30 exercises of each topic. Therefore, exercises would hardly repeat if the student plays again. To pass to the next level the student must correctly solve all the mathematical exercises in the stipulated time, which is 10 to 20 minutes according to the level. As mentioned, the purpose is for the student to have fun playing and at the same time learn Algebra, perhaps unwittingly.

As a guide to comply with the previous gameplay, storyboards of each level are made. To do this, scenarios based on the cities established for algebraic topics are proposed, which do not follow 100% of the original layout of each one, but the characteristic places and monuments are preserved. So, they can be instantly identified by the students. A short description of each level according the storyboard is given below.

- Level 1: Algebra basics - Egyptian pyramids, Egypt. The scenario represents The Valley of the Kings, where the Tomb of Tutankhamun is located. It was the principal burial place of the major royal figures of the Egyptian New Kingdom. There is also the Giza Pyramid Complex, that consist of the Great Pyramid of Giza (Cheops), the Pyramid of Khafre (Chephren), and the Pyramid of Menkaure (Mykerinos), as well as the great Sphinx of Giza. At this level, the character must collect ancient objects which have letters or numbers, to form the simplified algebraic terms that are requested in temples and pyramids. The similarity between hieroglyphs and numbers or letters, make it difficult to quickly find the terms.
- Level 2: Algebraic operations – Paris, France. The tour starts at the Eiffel Tower and ends at the Arc de Triomphe, among them are the Champs Elysees, at the far right is the Louvre Museum and on the far left there are Baroque Buildings. Paris is often referred to as "The City of Light", so the atmosphere is nocturnal with many lamps. To obtain the didactic material, the character must approach the lamps, which have a sign with a written polynomial operation that must be solved. This is done by spheres of light of different sizes and colors that fall slowly, each of them has algebraic terms. The character must take the spheres that form the correct result. If two incorrect spheres are taken, a new polynomial operation appears on another lamp.
- Level 3: Special products and factoring – Moscow, Russia. It is in the Red Square. There are different buildings around, such as: The Saint Basil’s Cathedral, the Kremlin with Lenin Mausoleum, and the State Historical Museum. Red Square is often considered the central square of Moscow since Moscow's major streets. To complete this level, the character must find the treasure chests that are scattered in the red square and surrounding buildings. They contain an equation and are opened only if the factorization or special product is successful. If the operation is incorrect, the treasure chest disappears and appears elsewhere.
- Level 4: First degree equations - Tokyo, Japan. It is a scenario of Shibuya neighborhood, a fashionable shopping and entertainment district. The tour is based on a circular avenue surrounded by buildings, with several roads to access a park, a Japanese temple and a shopping center. The character must walk through the food stalls in the street, as well as the various department stores that are inside the mall to buy things in them. The price to be paid is obtained by solving a first-degree equation. Along the way, there are coins that are used to pay for items. Enough coins should be taken, because if the money is not enough at the time of payment, some items should be dropped, and a new equation must be solved.
- Level 5: System of equations – New York, USA. The stage is located in the streets of the city, with the characteristic stalls of hot dogs and hamburgers. There is also the Statue of Liberty, a gift from the people of France to the people of the United States. In addition to a part of the central park with the zoo and the souvenir shop inside. The character must go to different places and solve problems of system of equations about the number of: animals in the zoo, objects in the souvenir shop, taxis on the street, etc. Due to the difficulty of the operation, at this level there

are clues about how to perform each step according to the chosen solution method, which is evaluated at the moment, in order to continue with the next step.

- Level 6: Second degree equations – Teotihuacan, Mexico. It is known today as the site of many of the most architecturally significant Mesoamerican pyramids built. The route is located on the Avenue of the Dead, where several pyramids and temples are found, such as: The Pyramid of the Sun, the Pyramid of the Moon, the Pyramid of Quetzalcóatl, The Ciudadela, The Palacio de Quetzalpapálotl. At this level, the character must climb the pyramids and enter the temples to find hieroglyphs of second-degree equations and solve them by the method of the general quadratic formula. Although there are several methods to solve this type of equations, by its simplicity only the method of the general quadratic formula is used. The formula is implicit in the game, so the elements must be put in the correct order only. This helps the exercises to be resolved more quickly.

At all levels, the algebraic exercises are shown with characteristic things of each place. Figure 2 presents the storyboards of levels 2 and 4.

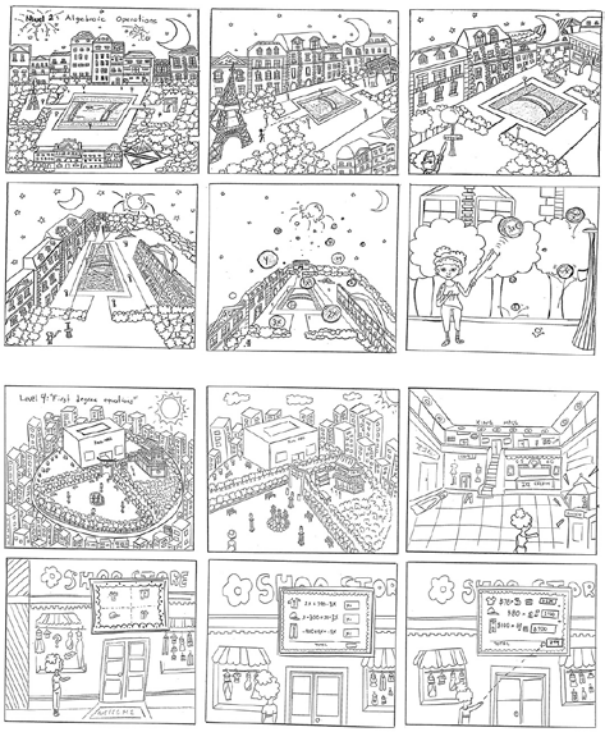

Figure 2. Storyboard of levels 2 and 4.

The next step is to make the 3D models of the buildings, shops, trees and other objects that appear in the storyboards. The procedure is like the one that is done to model the character, except by the process of assigning joints to generate movement, since they are objects that remain static.

The first thing to define when modeling starts is to have a scale of 1 unit per meter (1:1) in the measurement system, as well as reduce the number of polygons to the maximum to make the modeling mesh more lightweight, to avoid disorder in the coordinates and minimize the loading time in the application. Reference images, or blueprints, are also obtained for the models. References are 2D images of one or more orthogonal views of a given object, which are inserted into each software view as a guide to modeling that object with greater accuracy and precision than modeling it with the naked eye. Usually, the three basic views (Top, Front, Left or Right) are enough to define the model in the best way. Once defined, the 3D model of each figure is made in Maya. To begin, a cube or cylinder on the screen is typically created and then, using various modeling tools, the various faces (polygons) of the cube must be gradually expanded in whatever basic shape is required.

After realizing the 3D model, its UV maps are obtained in coplanar images, which allow its editing to give it color or texture. In this step, it is verified that each plane contains only four vertices, reason why some must be united without damaging the initial position and the form of the geometry. Then, the map is created based on the direction of the normal lines with regard the object and its faces.

Once the maps are finished, they are edited in Photoshop to put different colors, materials, textures, roughness, etc., according to each object to later export it to Maya again. The texturing requires a lot of dedication, since it must be a very detailed and meticulous work.

The following is to assign lighting to 3D models using lights of various types, such as: punctual, directional, area or volume. The purpose of lighting is to generate more realism to objects.

Rendering is done at the end, which is the processing of everything that is the polygon, shadows, reflections, lighting, etc. to generate realistic images, which taken from different angles ensures that 3D models meet the requirements. For this process, the rendering engine called Mental Ray is used.

In general, the digitalization methods used in this text comply with the following steps: presentation of the needs, choice of techniques to be applied, acquisition of field data, data processing, quality control and delivery. Figure 3 illustrates the process of creating some 3D models for levels 1 and 5.

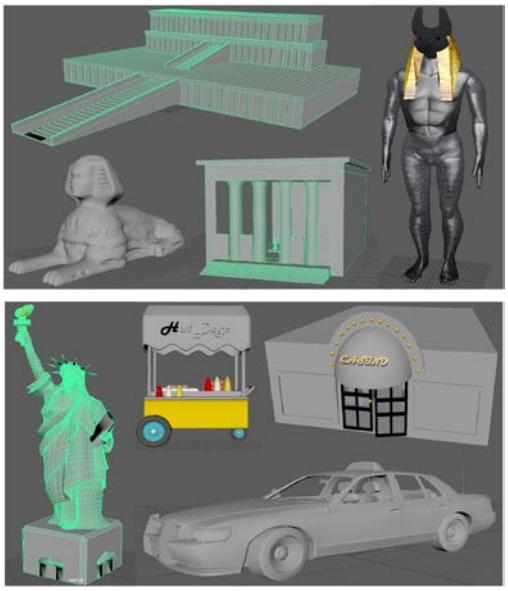

Figure 3. 3D models of levels 1 and 5.

Once all 3D models of buildings and objects have been created, they are exported to the virtual environment, which is made in Unity, software that provides the tools for developing and creating video games. Unity is structured by handling and creating scenes for the development of the desired application. A scene can be any part of the game, in a level of the game or a certain area. It starts with a blank space in which it is possible to shape everything by using the tools of unity. It also allows the importation of materials, 3D models, textures, sounds, etc. from other development engines, including Maya. In Unity, all the development of the city is done, and the objects are placed in the correct position according to the storyboard.

The first step is to create the terrain, which begins as a flat mesh, and through various functions is modeled and sculpted to get the right geometry. Once the desired look is obtained, several textures can be applied. Then, imported 3D models are placed. It is important to continue with the scale used in the creation of the character and other 3D models, since the compatibility with the scenario depends on it, as well as a good presentation. To fulfill this point, the view of the game is used, which allows to preview the game from the perspective of the player or maximizing it to full screen. It also allows to see the game in motion to check its proper operation. As with 3D models, the environment should be illuminated with the same light intensity, although this may vary according to the textures of the terrain. Finally, the sky is added to the scene, as well as mist, rain or dust effects that are needed at some levels. Figure 4 shows the creation of the virtual environment for levels 3 and 6.

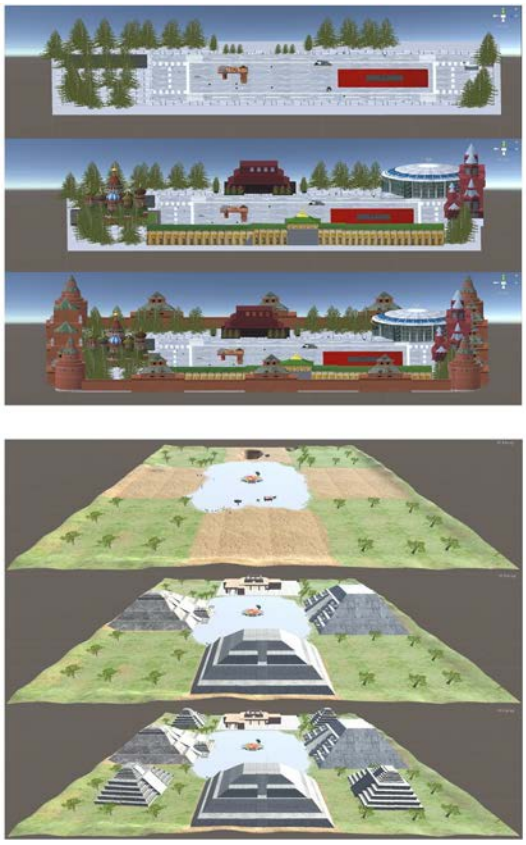

Figure 4. Virtual environment of levels 3 and 6.

Also, in Unity the programming of the character and some objects are made so that they have capacity of movement. Colliders are placed on all objects so that the camera cannot penetrate them and be as real as possible. Following with the programming, the background music is put together with the sounds for certain elements like jumps, steps, blows, etc. Programming scripts are done in C# language. Figure 5 presents part of the code used for the character to have movement.

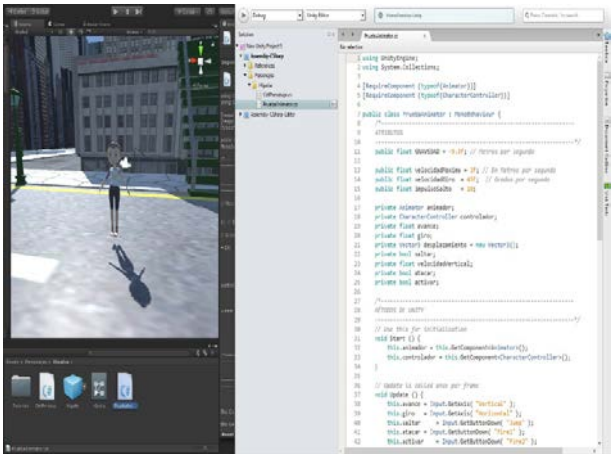

Figure 5. Code used for character movement.

Finally, the testing is performed to find and solve problems that exist in the video game, as well as to

verify various aspects, such as: reliability, efficiency, portability, scalability, maintainability, compatibility, usability and capacity. In this step, the character is introduced on stage to choose his position in front of the camera. The best position of the camera is behind the character, and slowly rotate it to this location if the character is facing

4 Performance of video game

Once the previous steps are done, the beta version of the video game is performed, which means that it is practically finished. This originates a version of the video game that can be used on a desktop computer or laptop. Figure 6 illustrates scenes of the video game already in operation.

Figure 6. Operation of the video game app.

As in any project, the measurement and evaluation processes seek to identify the effects, impacts and efficiency in the development of the video game. If it is not measured and evaluated there is no feedback, the results are not known, nor the weaknesses and strengths are identified.

To demonstrate the efficiency of the video game, 4 high school groups that were taking the subject of algebra were asked to play it. Each group is made up of approximately 30 teenagers. All students mentioned that they had never played an educational video game, except for similar mobile applications downloaded by their parents to improve their skills in general, so it is a field with a lot of future. Before the students started using the video game, they were given a short test to measure their algebraic knowledge. The test consisted of 5 similar exercises to those in the video game. The results were not encouraging. From a total of 118 students: 8 got 5 correct answers (ca), 23 got 4 ca, 43 got 3 ca, 28 got 2 ca, 12 got 1 ca, and 4 did not get ca. The purpose of the session was that after playing the game the students will answer a similar version to the initial test and improve their scores. Figure 7 presents the applied test.

Algebra test

1. Find the value of the following statement:
   $12+3\{-6+2[5-4(3-2)+5(7-8)]-5\}$
2. Perform the following operation.
   $\left(\frac{1}{2}x^2-\frac{3}{4}+\frac{1}{3}x^3-\frac{2}{3}x\right)\left(\frac{1}{3}x^2-2+\frac{1}{4}x\right)$
3. Factor the following expression.
   $6y^2+13y+5$
4. Simplify the following sentence.
   $\frac{6x^2y-12xy^2}{x^2-4y^2}$
5. Find the value of x in the following equation.
   $8x-(6x-9)+(3x-2)=4-(7x-8)$

Figure 7. Algebra test.

Like all first times, the start of the game was slow and doubtful for the students. But after playing for a while, they improved and got used to the stages. Students used the video game for about an hour. The game worked perfectly, no failures or shutdowns. Figure 8 shows the moment in which students test the operation of the video game.

Figure 8. Students playing the math video game.

It is noteworthy that almost 85% of students (97 of 118) could complete one level of the game on time. Some of the comments at the end of the session were: "It's a fun game and it helps to reinforce the knowledge I gained when I studied algebra", "When I hear the word mathematics I associate it with difficult and boring, but the game

was good," "I was close to take out my calculator", "I could not remember how to solve the exercises but I saw the clues and I could complete the game", "With this way of learning I would attend to classes daily", "I liked the scenario and the buildings of the game". The students left the classroom talking about the video game and commenting how they solved a certain operation, which means that the video game generated interest of them towards algebra and mathematics. Later, all they returned to the classroom to solve another version of the test. The results were favorable since: 18 got 5 ca, 39 got 4 ca, 45 got 3 ca, 13 got 2 ca, 3 got 1 ca, and 0 did not get ca. Looking at the results, it is remarkable that the video game helped the students to review the topics seen in class and to increase their knowledge. Table 1 contains the complete information of the applied tests.

Table 1. Comparison between both tests.

Group	First test						Total
	0 ca	1 ca	2 ca	3 ca	4 ca	5 ca	
A	1	2	7	13	7	2	32
B	0	4	5	11	5	3	28
C	3	3	10	9	4	1	30
D	0	3	6	10	7	2	28
Total	4	12	28	43	23	8	118
%	3.38	10.16	23.72	36.44	19.49	6.77	99.96

Group	Second test						Total
	0 ca	1 ca	2 ca	3 ca	4 ca	5 ca	
A	0	0	3	14	11	4	32
B	0	1	2	10	9	6	28
C	0	1	6	11	9	3	30
D	0	1	2	10	10	5	28
Total	0	3	13	45	39	18	118
%	0	2.54	11.01	38.13	33.05	15.25	99.98

ca: correct answer(s)

Weeks later, the students' teachers reported that 95% of them passed the algebra course, and that the use of the video game influenced their perspective on mathematics. Besides, it served so that they knew some applications that can give to those subjects. Teachers requested the video game to use it in future classes, because they consider it an innovative tool for students and even consider using it as a means of evaluation.

The methodological strategy implemented during the development of the video game, fulfills with attracting students to learn from their knowledge and skills, in addition to increasing their interest and developing thought processes, breaking the stereotype that mathematics cannot be taught in a fun way. This video game will be provided to schools in the region as an additional educational resource. The goal is for teachers to use it at the end of each topic and serve as feedback to students. It should be mentioned that it is not necessary to play the levels of the video game in order. For this, a graphical interface is designed that allows the student to select the level that he wants to play, and thus, focus only on a specific topic.

The use of video games in classrooms has been a topic of discussion in recent years. Supporters mention that students should be taught with things that are attractive to them. It has been proven that with the advancement of technology, traditional methods have lost strength and interest, so it is necessary to use computers, cell phones and videogame consoles to approach students to didactic topics. Detractors mention that video games have problems of violence, addiction, isolation and sexism, so they divert attention from priority educational issues, and generate aggressive or pathological behaviors. The reality is that opinions voiced by the players about the video games are extremely varied, ranging from curiosity through amused indifference to fascination; although the general opinion is one of acceptance [12].

The truth is that people cannot ignore the changes that occur in society and the impact they generate in the way that teaching is provided, with teachers using ICT as a didactic strategy. This new condition may be an alternative to break with the monotony and boredom that characterizes certain school spaces that have little congruence with what happens outside of them. In [15], Green and McNeese suggest that teacher reluctance to incorporate games into curriculum is incongruent with the influx of high school and college students who grew up with games. Digital games remain an option for enhancing educational curricula in the interest of attracting and maintaining attention and to increase retained knowledge [16].

5 Conclusions

The design, development and implementation of an educational videogame on basic school algebra is described in depth. The aim is for the students to perform a daily activity that they enjoy, like playing video games, and at the same time to reinforce their knowledge about algebra. Activities such as gameplay, storyboard, production of character, objects and scenarios, audio design, programming, testing and Beta version are considered. The process is very time consuming and complex, since the details are taken care of when 3D modeling and virtual scenarios are done. They must also be lightweight files so that the video game compiles

fast and does not occupy too much space in the installation. When testing the video game with 4 high school groups that were taking the subject of algebra, 97 of 118 students finished one level in the stipulated time and improved their score in two written tests they did. In addition, the comments were positive, as it served as feedback and made them strive to solve the mathematical exercises. Therefore, it is a teaching learning method with a promising future.

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