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Mathematics Game e-Library for Elementary School, Study Case: Mexico

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Abstract

One of the most relevant subjects for the intellectual formation of elementary school students is Mathematics where its importance goes back to ancient civilizations and which its importance is underestimated nowadays. This phenomenon occurs in Mexico, where 63.1% of the total population of elementary school students between the third and sixth grade have insufficient/elemental level of mathematics knowledge. This has resulted in the need to use a new mechanism to complement student's classroom learning. With the rapid growth of wireless and mobile technologies, the mobile learning has been gradually considered as a novel and effective form of learning due to it inherits all the advantages of e-learning as well as breaks the limitations of learning time and space occurring in the traditional classroom teaching. This project proposes the use of a *Mathematics Game e-Library* integrated by a set of games for mobile devices and a distribution/management tool. The games are developed for running on mobile devices and for cover the six competencies related with the mathematics learning approach established in Mexico. The distribution/management tool allows students to reach contents according to their needs; this is achieved through a core engine that infers, from an initial profile, the games that cover the user's knowledge gaps.

Keywords: mathematics; video games; movile learning; e-learning.

1. Introduction

It seems natural that most of the population is unaware about almost every issue related with mathematics and the interaction with it is limited to the basic rules. Mathematics is used in the daily life,

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and virtually in all branches of human knowledge, and due to this, is necessary to understand and analyze the wealth of information that is generated in the environment.

Mathematics has, since ancient civilizations, an important role in the intellectual formation of children. All school subjects contribute to the achievement and to the development of intelligence, feelings and personality, but mathematics has an outstanding place in the development of intelligence [1].

Since 2003, Mexico has implemented the usage of technology for education within public and private schools at all levels, from elementary to higher education. Mainly it has been implemented throughout the use of desktop computers with special software that provides diverse resources like bibliographical references, video, audio, fixed maps, images, interactive activities and material of other educative programs. Contents from Microsoft Encarta Encyclopedia have been included also. [2]

Despite the efforts made so far, it has become clear through ENLACE test that the educational level of students is barely improving. ENLACE test results have clearly identified which are the learning levels of the elementary school students in various subjects of basic education, such as Spanish, Mathematics and Science [3].

ENLACE test was applied to 8’631,091 students from third to sixth grade in elementary school in 2011, and the results obtained show the low impact of the different programs that the Ministry of Public Education has implemented and make evident the challenges and the areas in which is important to obtain significant advances. It is important to mention that ENLACE test covers the 100% of students in Mexico.

As mentioned above, Table 1 shows a historic results record for the test applied in elementary school since 2006 to 2011.

Table 1. ENLACE test results [3]

Year	Achievement Level (%)				
	Insufficient	Elemental	Good	Excellent	Students
2006	21.0	61.4	16.0	1.6	7’506,255
2007	20.2	57.5	19.0	3.3	7’962,825
2008	22.8	49.5	23.0	4.7	8’108,694
2009	20.3	48.6	24.9	6.1	7’810,073
2010	19.7	46.4	25.8	8.1	8’323,728
2011	16.5	46.5	25.9	11.0	8’631,091

1.1. Extra School Education

Learning is not restricted to the time spent at school. It begins at birth and continues all your life [4]. Francesco Tonucci argues that the most important experiences for personal development in childhood and youth are lived outside school. A truly meaningful education should also be built on the student’s informal experiences that happen before or at the same time that school [5].

The present pattern, in which we have education at the beginning of our lives, is changing. Lifelong learning is becoming part of modern life. This is because rapid technological change and growth in information require ongoing learning. [4]

In modern context, the individuals evolve in an environment strongly influenced by the presence of diverse artificial and technological elements. Daily opportunities for students to have meaningful and relevant experiences outside the classroom are very high, turning the classroom, which is one of the most important sources of knowledge, into a secondary source of information for students [5]. New Information and Communication Technologies (ICT) are the modern delivery tools of knowledge for

education, making possible what was not before. Radio, television, computers, electronic devices, games and Internet are strongly embedded in the everyday life of students.

The traditional teaching paradigm, where formal and non-formal education are treated as a mutually exclusive, must be changed and turned into a new learning paradigm where the boundaries between formal and non-formal education disappear in order to achieve a meaningful and relevant learning.

To achieve these objectives both –the improvement of academic standards in math in elementary school children– and –the introduction of a new mechanism which allows to achieve a level of excellence through the elimination of the boundary between formal and non-formal education–, are proposed the use of a set of large scale resources (games) as well as a distribution/management tool for providing these resources in manner and in time when they are required to those who need them.

The first element proposed is a set of games developed to meet the next specifications. These specifications have been created based on the study of the state of the art of gaming, the characteristics of the Mexican population, and initial test results of the games with students.

- Short and focused on a single competency, to enable the student to focus on a particular topic at a time;
- Graphical user interface simple and pedagogically evaluated;
- Cases with formal reasoning;
- Cases randomly generated to prevent the student memorize the answers to problems;
- Challenging content and generating competition among students using the game, i.e., cases with different levels of difficulty;
- Multiplatform development.

The second element is a system able to distribute and manage these games and make them reachable for students according to their knowledge gaps.

2. Video games for Teaching

There is a need to integrate more efficient mechanisms in non-formal environment for students and increase learning opportunities beyond the classroom. Mechanisms with great potential are video games.

It has been observed in many studies, like [6], that the video game phenomena can be used in advantage to the formal learning process outside school, because video games are very attractive to kids, and their use as teaching tools is plausible. In addition, others studies like [7] have shown that video games are widely used in daily life of Mexicans kids, showing that 64% of the surveyed people own a video game console since three years ago, 55% play from one to three days a week and 72% play between one and three hours daily.

On the other hand, the rapid growth of wireless and mobile technologies has resulted in the mobile learning that has been gradually considered as a novel and effective form of learning because this inherits all the advantages of e-learning as well as breaks the limitations of learning time and space occurring in the traditional classroom teaching [8].

Thus, the intersection among education, video games and mobile devices results in a niche that can produce an improvement in the learning of mathematics in Mexico.

2.1. Implementation process of video games to the identified competencies

For the development of video games we have identified, through the study of textbooks distributed by the Ministry of Public Education (these books are developed with adherence to educational reforms, and today based on competencies), a set of competencies for mathematics learning covering all the topics for sixth grade in elementary school.

Table 2 shows these competencies and specific knowledge areas they cover.

Competency	Knowledge areas	Description
The numbers, relationships and operations	Operations	Use basic operations to reach a particular goal.
		Resolve operations mentally and prioritize them.
	Decimal system	Operations and use the decimal point.
	Fractions	In relation to a unit, determine what fraction corresponds to certain questions.
Geometry	Shapes and polygons	Relate the figure appearing under his name respectively.
	Handling of solid figures	Creation of new figures from points or other basic shapes
	Cartesian plane	Find an objective from the motion within a plane.
Measures and Conversions	Lengths	Application and comparison of the measurement units of length.
	Volume	Application and comparison of volume measurement units.
	Weight/mass	Application and comparison of the measurement units of weight/mass.
	Perimeters	Determining the shape of geometric figures from its dimensions.
	Areas	Determining the area of shapes based on its dimensions.
	Time	Application and comparison of the measurement units of time.
Information processing	Graphic representation of results	Creating tables and diagrams to interpret information and amounts from goals.
Processes of change	Patterns	Proportionalities equivalent.
	Values of unity	Find an objective from certain indications of a plane.
	Cross product	Application of operations using the cross product.
	Percentages	Use percentages for achieve goals.
The prediction and chance	Combinations	Resolution count problems and use the tree diagram.
	Odds	Application of operations through chance games.

Based upon these competencies, we have developed a set of 16 video games, which include subsets of mini games, obtaining about 25 games and mini games. Briefly we will be releasing another nine video games. Next, Table 3 and Table 4 show the developed and on-development video games and the knowledge areas they cover.

As you can see on the mentioned tables, the video games are being developed to be used on multiple platforms and devices. Java ME games are intended to cover low-end mobile phones; .NET games try to reach the students who have access to PDA's; Flash games are intended to be used on platforms like iPhone, iPad, PC, Mac and some Flash enabled mobile devices; OpenGL games can be distributed to platforms like Windows, Mac, iOS; and Android games using AndEngine for OpenGL covers all the Android devices in market. Screenshot for some video games can be seen in Fig. 1.

The development process used to create all the video games has the next stages and activities:

- Storyboard. In this stage we will perform *conceptual* and *detailed creation* of the video game, and *musicalization*. The initial sketches are revised to be passed to the next phase.
- Art. In the art stage, the *initial sketches* (characters, environments and objects) *are completed* and takes place an improvement thereof.
- Digitalization. This stage takes care of *creating the characters*, *environments* and *objects* in graphic design tools. Also is in charge of *digitalize sounds* and *music*.

- Programming. The programming stage *creates* or reuses the graphics engines for *sequences*, *animations*, *physics*, etc.; *layouts* for 3D scenarios and performs the *integration* of video game *menus* and *databases*.
- Testing. This stage is responsible for carrying out the collection of opinions for *marketing the product*, get the *statistics of effectiveness and efficiency of the product*, and perform *preventive maintenance*.

Table 3. Developed and on-development video games.

Video games	Competencies	Knowledge areas	Language	Target devices
pokeMath	The numbers, relationships and operations	Operations	JavaME	Mobile phones
MathChallenge	The numbers, relationships and operations	Operations	.NET	PDA's with Windows Mobile
	Measures and Conversions	Weight/mass		
DS3A	The numbers, relationships and operations	Operations	JavaME	Mobile phones
SpaceMath	The numbers, relationships and operations	Operations	Flash	iPhone, iPad, PC
Fracciones	The numbers, relationships and operations	Fractions	JavaME	Mobile phones
GeoBodies	Geometry	Shapes and polygons	JavaME	Mobile phones
CubeLand	Geometry	Handling of solid figures	OpenGL	Various
Submarino	Geometry	Cartesian plane	JavaME	Mobile phones
GolfMeter	Measures and Conversions	Lengths	JavaME	Mobile phones
miHuerta	Measures and Conversions	Volume	JavaME	Mobile phones
Áreas	Measures and Conversions	Areas	JavaME	Mobile phones
Ubicación	Processes of change	Values of unity	JavaME	Mobile phones
Regla de Tres	Processes of change	Cross product	JavaME	Mobile phones
Kaxan	Processes of change	Percentages	JavaME	Mobile phones
WWE	The prediction and chance	Odds	JavaME	Mobile phones
Marcianos	Geometry	Shapes and polygons	Android	Andorid devices

Table 4. On-development video games.

Video games	Competencies	Knowledge areas	Language	Target devices
WeightyWork	Measures and Conversions	Weight/mass	Flash	iPhone, iPad, PC
Time Rider	Measures and Conversions	Time	JavaME/Android	Various
Time Champ	Measures and Conversions	Time	JavaME/Android	Various
Jinete Solitario	Measures and Conversions	Lengths	JavaME/Android	Various
Perimeters	Measures and Conversions	Perimeters	JavaME/Android	Various
Softy	The prediction and chance	Combinations	JavaME/Android	Various
MathFractions	The numbers, relationships and operations	Fractions	JavaME/Android	Various
X Thor	The prediction and chance	Odds	Pending	
X Osiris	Processes of change	Patterns	Pending	

3. Distribution/Management Tool

Once the knowledge acquisition problem in the area of mathematics for basic education indicated above and the use of video games for mobile devices like a proposed solution for this problem has been defined, the creation of a scheme in which the video games by means of a repository are distributed/managed to be supplied in an efficient way to the possible students according to their needs, that is to say, we suppose that some student has deficiencies in his/her abilities to solve problems related to the crossed product and nevertheless its knowledge related to geometric bodies is acceptable or excellent, thus we would need some mechanism within the video game Distribution/Management Tool that supplies those games on which a particular interest exists by the student, in other words, those video games that help to the student to improve their knowledge or abilities in connection with some subject in which is not very efficient. Due to this, is proposed the creation of a Semantic Web scheme which will allow the management of knowledge in an efficient way.

(a)

(b)

Fig. 1. (a) .NET video game screenshots, (b) Flash video game screenshots.

3.1. OWL Ontology

The use of ontology is carried out mainly to capture knowledge referring to some domain of interest. Ontology also describes to the concepts in the domain of interest and the relationships that can exist between these concepts. The most recent development in the standard of the ontological language is the

OWL of the "World Wide Web Consortium" [9] [10] which present a series of rules and conventions to work in these kinds of models.

3.1.1. OWL Ontology components

Usually, ontology is integrated of three elements that are:

- *Individuals*. The individuals represent the objects of the domain of interest, like for example people, animals, countries, abstract organizations, etc.
- *Properties*. The properties are binary relations between individuals to be able to connect them somehow, suppose that we have the individuals student and game, then the property that would relate them would be "is used", giving as result that a game is used by a student.
- *Classes*. Classes are sets of groups, a certain type of individuals with similar characteristics, for example, consider the class student, which groups all the individual students which can be simultaneously constituted by subclasses, such as students of first grade level, students of second grade level or students of last grade level.

3.2. Ontological Representation for Education Video games

In the field of Web applications development, there are different mechanisms for the representation of ontological models; in particular, within this research was used Protégé 4 software for the edition of ontology [12], in which it have been represented the scheme of video games through an OWL Ontology.

In our class definition, initial games were declared as our objects of interest, that is to say and just for representation we declared four games, independent of each other and in theory created and managed by different videogame programming groups within our development team, which are: BusquedaDelTesoro (Treasure Hunt), Cubos (Buckets), ReglaDeTres (Crossed Product) and Submarinos (Submarines).

In this way equivalent classes can be created for video game in a way that the reasoner can make an inference according to those classes and also can create an inference tree (Fig. 2).

Once proven our ontology, we can work with the same within a scheme of XML- RDF files, which shows the ontological description of the videogame later to be implanted within our structure of video game Distribution/Management Tool.

One of the advantages of using an ontology such as OWL is to be able to make use of some reasoner, which allows creating inferences according to pre-established rules for the solution of problems. Protégé can use four different reasoners that classify and verify the consistency of the created ontology, for the study case in this research in particular it was used Fact++ [11], which is a logic description reasoner compatible with OWL and that at the same time adapts better to our set of rules for the creation of inferences.

Once defined our games, we can offer them towards determined group of users to be able to customize its use.

3.3. Video game Distribution/Management Tool

Once created the ontology for the organization and as well as the creation of inference of video games, it is necessary to create a structure to manage the video games and to be able to provide them in an efficient way to the clients (students). The goals of the video game manager are:

- Record and organize video games,
- Provide the games as well as to create profiles of preferences for users; and
- Update the information of existing video games and notify it to the users.

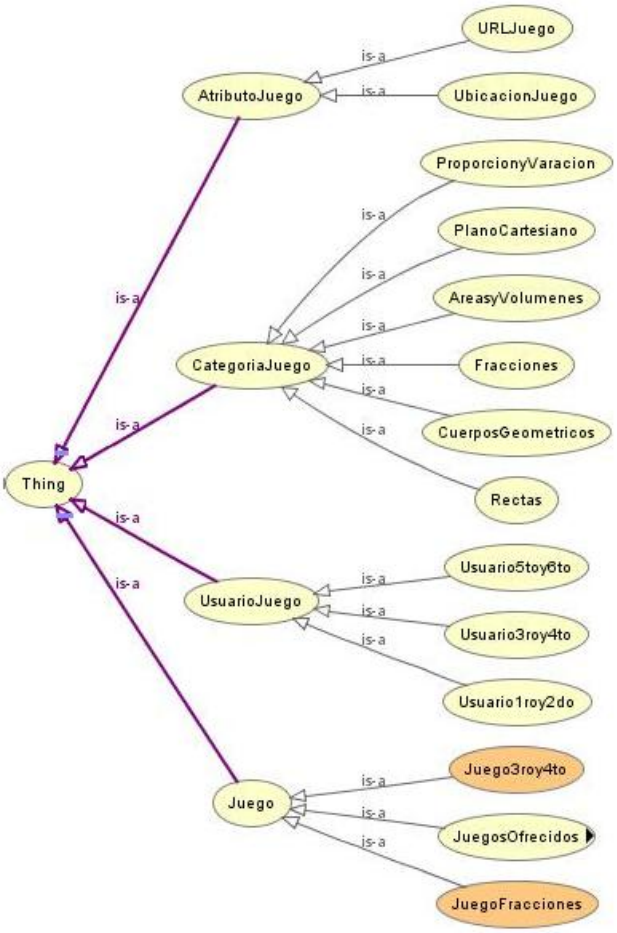

Fig. 2. Inference tree

Another part of the video games Distribution/Management Tool is events. The main idea on which is based the use of events and notifications is that an object (video game) can react to the changes that happen in another object through events (update of video games) that are notified to each other within the network [13].

For this research in particular a structure has been created based on this principle where the video game Distribution/Management Tool is constituted by two main components that are, the *Game Provider* and the *Game Notifier*. Within the *Game Provider* a catalogue of games previously registered is obtained as result of the above process, this catalogue will be organized subsequently according to the scheme declared in the ontology to be given to the *Game Notifier* which will inform to the clients that are interested in one or more games as it can be seen on Fig. 3.

On the other hand our video game Distribution/Management Tool through Game Provider, will receive requests to register or update video games, for example, suppose that the game Treasure Hunt registers continuous changes that modify its category, according to the principle of events and notifications, whenever the game is updated it is generated an updating event which notifies the subscriber of this change, through the included reasoner, where it will infer the possible clients who are interested in the

update of the video game, still more, the same clients will be able to register those games in which they are interested making use of the Game Notifier, for subsequently updating the Ontology and create new inferences.

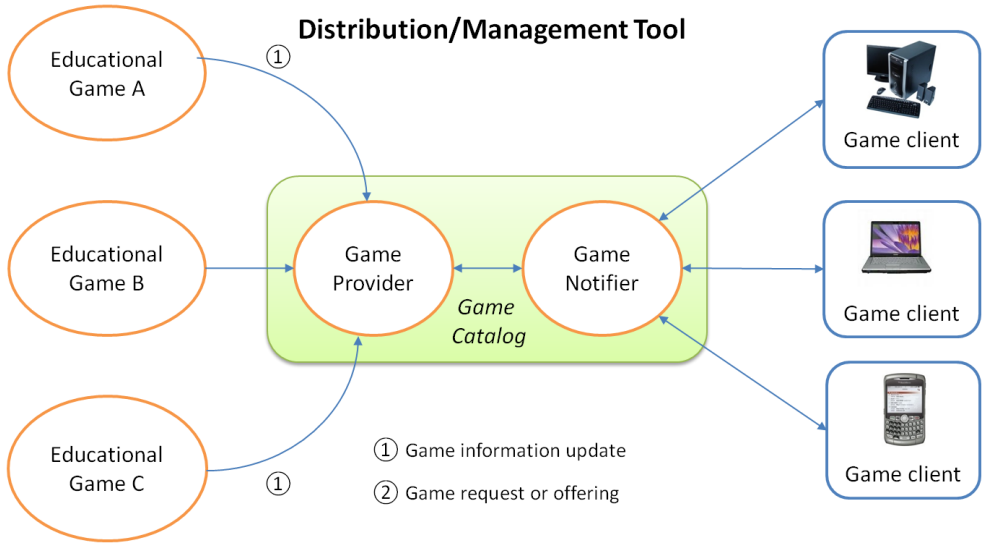

Fig. 3. Video game Distribution/Management Tool Architecture.

It is important to mention that the video games Distribution/Management Tool will receive events and notifications of the video games to create or to update the same as well as of the clients for the registry of games within their profiles.

4. Results

After the initial production phase of video games, we proceeded to test with a group of students from sixth grade of elementary school from the “Federal Rural Cuauhtémoc Elementary School” (see Fig. 4) located in the community of "La Paz Ojuelos of Jalisco" in the state of Jalisco, in order to study the impact on the learning level of students exposed to video game use.

The process performed for the test was as follows:

- We identified potential schools.
- Tests were designed for initial and control evaluations. The tests were designed to evaluate knowledge level of students in the next knowledge areas: Areas, Handling of solid figures, Fractions, Shapes and polygons, and Crossed product.
- School was selected.
- Students group was selected. The group was divided into two parts; taking into account that in both groups, students’ average grade must be equally distributed, i.e., the group was divided according to the average grades of the students.
- Initial evaluation was applied to all students.
- The test group used video games in one-hour sessions twice a week for four weeks.
- At the end of eight sessions, we applied the control test to identify the impact of video games use.

Fig. 4. Federal Rural Cuauhtémoc Elementary School students.

Fig. 5 shows the overall result of the students in different areas of knowledge tested. The diamonds line displays the results obtained in the initial examination, and the squares line displays the results of the control evaluation. It is observed that in three areas was a significant improvement in the level of knowledge; in Fractions there was a slight improvement and in the remaining area, Crossed Product, there was a decrease.

The improvement in the areas of Handling of solid figures, Areas and Shapes and polygons shows that the use of video games help to improve the knowledge level of students who use them.

The Crossed Product and Fractions areas show an interesting behavior which is explained in the following paragraphs.

In the case of Fractions, the staff responsible for conducting the tests observed that the video game graphic design was unattractive, resulting in little interest in using the game by the students.

The Crossed Product area presented a different condition: the problems presented by the game were not randomly generated, but the game had a question bank which students memorized. Thus, the students responded to the problems with memorized answers in last sessions, leaving aside the formal procedure for the resolution of the exercise.

Fig. 6 shows the behavior of grades for the knowledge area of "Areas" and “Crossed product”. The results displayed on the left graph show a strong trend of improvement in the level of knowledge. The examination results for Crossed Product knowledge area are shown on the right graph and, as can be seen, the trend line for the control evaluation shows a decline in student scores, this due to the use of a questions bank instead of randomly generated questions.

5. Conclusions and future work

This study has focused on developing a set of video games and a tool for the distribution / administration of those video games through a web portal. The process used to produce the resources integrates aspects of software engineering and pedagogy to ensure that usability and functionality of the products are suitable for students.

The tool mentioned in this article was developed to cover aspects of storage, sorting and distribution of video games produced. The tool then provides a mechanism that will allow users to enter a profile, which includes the areas of knowledge who want to strengthen, in order to recommend the most appropriate resources for that purpose. Added to this, the tool will allow game developers manage the products, either

by adding them to the repository, updating or changing their classifications. Importantly, the tool can be used for any educational resource, not just video games.

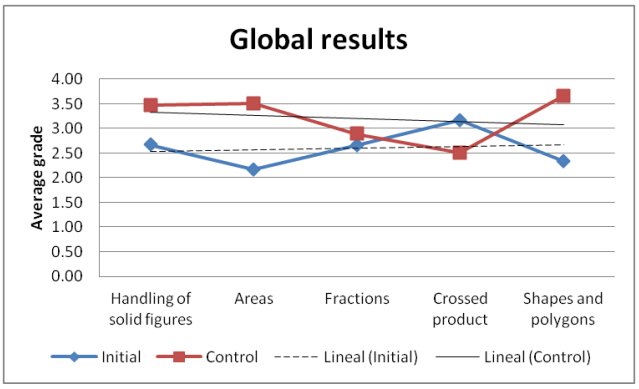

Fig. 5. Test overall results, displaying average grades obtained in initial evaluation vs. the grades obtained in control evaluation.

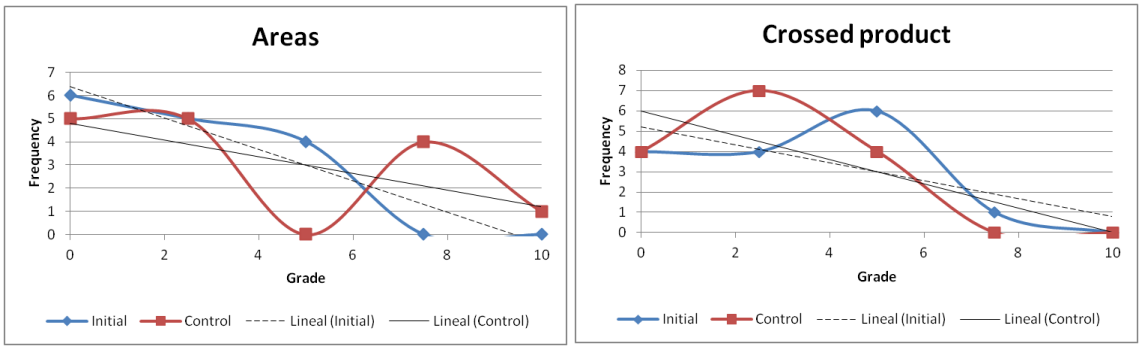

Fig. 6. Grades obtained for the "Areas" knowledge area. This figure displays tendency lines for the initial (dotted line) and control (solid line) examinations.

The results obtained show that video games are a resource suitable for teaching mathematics in elementary school, since children are very interested in their use. Similarly, it is observed that the use of video games increases the level of knowledge of students significantly in a short period of time, so it can be established that the continuous prolonged use would further improve levels of knowledge.

Therefore, we can establish, based on observation of children in the test, that video games are a highly effective mechanism for teaching, since students are very attracted to the use of technology and, depending on video game design, can spend a long time using the resources, moreover, the time spent playing video games is a time in which focus exclusively on this task so that the absorption of knowledge is greater.

Application of the tests showed that the design of video games is very important because the design will determine the interest level of use, and enhancement of knowledge in the student. In this study we

observed that some features of video games developed were not identified in full, so this study also allowed us to establish fully the features that must have an educational video game.

This research will continue in development, and the next steps and publications include topics related to the process of game development, testing video games for a full school year (a period of one year), studies / publications GUI usability in educational games, publications of detailed development processes, among others.

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