# Ar-Math: Augmented Reality Technology Applied for Education

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**Abstract.** Currently, technology opens the doors to a new generation of methodologies in the teaching of various subjects. "Serious games" are a tool that allows students to learn while playing, which has several cognitive and social benefits. Augmented reality by its sensory element becomes a tool suitable for application in serious games for young ages. This paper presents a serious game for teaching numerical place value for children up to 6 years, we called as AR-Math.

**Keywords:** Teaching · Mathematics · Positional value · Serious game · Augmented reality

## 1 Introduction

The international evaluation PISA [8] develops the evaluation to students in mathematics, science and reading; in mathematics, both Mexico and Ecuador score below average. The educational models are focused on 4 essential competencies in mathematics: the skills and competencies to solve problems independently and autonomously; communicate information regarding mathematics; validate the procedures and results; and finally manage techniques so that they are more efficient. In this last point, there is a concern about the proper use of TICS in the classroom to improve the procedures to solve problems, always promoting autonomous and collaborative study. One of the vulnerable areas is the issue of place value of the number, so this project aims to define an application that favors autonomous learning, so that they use the decimal numbering system to express quantities, to expand and deepen knowledge, way that the understanding and efficient use of mathematical tools is favored.

Likewise, the document "Programas de estudio 2011 guía para el maestro" [18] of the Secretaría de Educación Pública in Mexico, has the purpose of improving the study of mathematics at the elementary school by helping children


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develop ways of thinking, which are most interested in common activities of life or starter's numerical or geometrical problems that are presented in classroom. It also intends to use different resources and techniques to improve procedures to solve problems, always encouraging on the one hand autonomous study but also collaborative work.

With the learning of mathematics, one of the objectives mentions that elementary school children should know how to use the decimal numbering system to express quantities, among many others in order to broaden and deepen knowledge, so as to increase comprehension and the efficient use of mathematical tools. Within the teaching of mathematics, project-based learning stages or problem solving are those that show a more noticeable benefit than others because they apply the use of a relevant tool, as well as the processes that students follow to build knowledge and overcome difficulties that show up in the learning process.

Currently, the learning process seeks improvements in the reasoning, so knowing formulas, algorithms and definitions are important only to use them as tools for solving problems rather than simply memorization. This is the reason why the learning processes in mathematics now takes more time. In this same line it is important that the child is the one who builds his own learning through the resolution of the problem situations by himself, being the teacher only an observer of the process and make questions to reinforce acquired concepts. These situations in the classroom are favorable because students feel more confident to express their ideas freely, reflecting on their acquired knowledge.

The school system in Mexico mentions 4 essential skills in mathematics. These 4 skills are aligned with the 4 competencies of the educational model of mathematics contained in the international evaluation of PISA. This are the same skills that are considered in the technological development of this project [2].

There are educational models focused on the student, in which the only responsible for the learning process is the student. The student creates and thinks for himself so he acquire confidence and discipline, this later helps the student to build other kinds of learning; this is case of the Montessori method. In this model, the teacher, as already mentioned, is only a guide for learning, encourages the student and applies tools in which the child learn in funny ways, leaving aside bad effect and complex processes. In the context of educational innovations, there are efforts to support learning processes in the classroom through the use of "serious games". Currently, technological tools allow software products to be conceived not as interlocutor, but as an instrument of action in a space in which conversations with real or virtual objects take place.

Recent research have prove that digital games can used as learning tools that motivate and generate curiosity resulting in an effective way to optimize learning and student performance [9]. Learning and student engagement due to the use of digital games in daily routines has been confirmed by several independent studies over the years, integrating games in different ages for teaching different assignments.

The present proposal focuses on developing a serious game based on technologies such as Augmented Reality (AR) [7] and Intelligent Algorithms (AI) will helps the learning of the topic of positional value for elementary school children. Thus, the idea of the serious game called Ar-Math is born. Ar-Math stands for augmented reality math. We intended to propose a game where young age kids would learn about positional value using augmented reality as it main component. The task kids are presented is to place tangible targets with numbers printed on them in the correct order so they form a random number. As they see the numbers in thought a camera, they would see animations with each character. The remainder of the paper is organized as follows: Next section presents an analysis of related work. Next, Sect. 3 describes a set of functional and non functional requirements identified for Ar-Math. This section also provides a description of the Ar-Math architecture. Section 4 presents the Ar-Math tool. Section 5 discusses a set of benefits and shortcomings. The conclusions and future work are presented in Sect. 6.

## 2 Related Work

Serious Games [1,6,16] are applications in which the user enters competition with the computer following a series of specific rules, which uses entertainment to promote learning in the user [19]. This kinds of applications combines video game elements, pedagogy and aspects of human computer interaction engineering.

Even if "serious games" themselves, could be considered as an oxymoron because "Games are inherently fun and not serious" [4]. In the context of serious games the enjoyable component of this works are the most important one [13].

The difference between serious game and video game, is that in a serious game, it is important to measure the learning acquired throughout it. A serious game consider a physical or mental challenge. In order to evaluate the mental challenge, it is necessary to incorporate a set of training and fun rules to reach the pre-established training objectives.

Studies on Serious Games show positive influence, especially on Primary school and Preschool students due to it multi sensory nature [10]. Recent research showed that with Serious Games students are more likely to be engaged to class, scaffolding their learning. Students also showed increased autonomy, independence, motivation and resultant self-esteem. Likewise, the authors have proven that Serious Games Based Learning add value in the geometric thinking learning which includes recognition, visual association, description/analysis, and abstraction/relation) [10]. How technology in education is used have changes considerably over time. In order to enhance education, new paradigms have appeared in classrooms [14,15].

There are endless applications of Augmented Reality. For example, Augmented Reality have been found useful in areas such as Human Computer Interaction (HCI), Computer graphics, vision, architecture, design, collaborative learning, production planning, engineering and gaming [3]. AR is not just a support that potentiate disciplinary learning, user develops skills like information sharing, collaboration and critical thinking [3].

Currently, the Augmented Reality (AR) technology makes it possible to create pedagogical content and digital textbooks. The applications can be used in tablets or smartphones and can be used by teachers and students in the framework of the joint construction of learning objectives. The augmented reality applied in software for education lies in applications to learn history, mathematics, chemistry, biology, anatomy, space, translations and gymnastics. This confirms that the most motivated and committed students always understand the subject better and learn faster using this technology [5,17].

## 3 The Proposed Solution

In order to specify and design the serious game in a flexible and effective way, we use a user-centered agile development approach (UCD) [12]. To achieve and comply with the use of this agile practice, we must consider compliance with the usability objectives and also ensure that the user experience is satisfactory while adhering to the agile principles of software development [11]. We also, adopt the life cycle of agile development to create the user interfaces, taking as a fundamental aspect the requirements of interaction, the profile of the user and their user context. This agile life cycle will allow us to obtain a usable and accessible interface. Its importance is that it is designed for development environments in which multidisciplinary teams with expertise in user experience (UX) and agile development, want to integrate user-centered design practices (UCD) and agile software development methods (ASD). UCD's approach [12] includes analysis, design and implementation where different concepts, techniques and evaluations are used in the field of human computer interaction (HCI) to guarantee efficiency, effectiveness and quality in the execution of learning tasks by users.

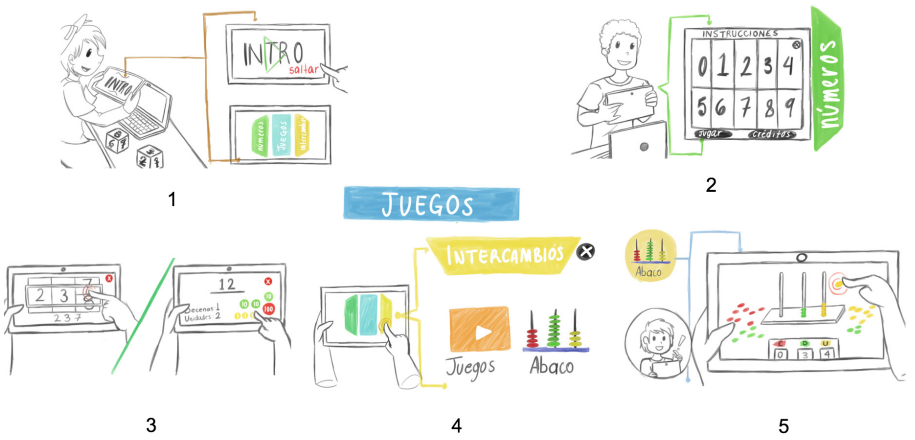


**Fig. 1.** Sketches made during requirements discovery.

### 3.1 The Functionalities of Ar-Math

We argue that the Ar-Math software would have the functionalities presented in Tables 1 and 2. Once we started applying the user-centered approach, we were able to discover the requirements of the application while we made some representations of the user interfaces that had developed developments. Figure 1 shows several sketches of the interfaces made. Panel 1 corresponds to the functional requirement "Start module". Panel 2 was used to describe the "Augmented Reality module". Panels 3, 4 and 5 where used to identifies the "Games" and "Exchanges modules".

**Table 1.** Functional requirements of Ar-Math.

| Nro. | Name | Description |
|---|---|---|
| 1 | Start module | The interface has a starting section for the user to choose three sections to perform: Numbers with Augmented Reality, Games or the Exchanges section |
| 2 | Augmented Reality module | The application will have a module where the children will access to the AR camera and visualize 3D models of numbers from 0 to 9. When a 3D number is shown in the AR camera the children will hear the name of the number too. The application recognizes all the numbers drawn in the cubes an show them with augmented reality |
| 3 | Games module | The application will have a module where the children can play 3D and 2D games that'll help them to learn more about counting numbers and units, tens and hundreds. The child can select different types of exercises |
| 4 | Exchanges module | To verify that the participant already dominates the issue of place value, the application contains this section. The application will have a module where the children can interact with an abacus. It is very important that in this section units are exchanged by tens and hundreds by any game |
| 5 | Emotion recognition module | The application must use techniques of Computer Vision and Artificial Intelligence to adapt the level of the game based on the emotiotional state of the user |

**Table 2.** No functional requirements of Ar-Math.

| Nro. | Description |
|---|---|
| 1 | The application needs to be installed in a touch device, such as a smartphone or a tablet with a camera in both sides of the device with at least 3 Megapixels |
| 2 | The application will have a design based on cartoon monsters and vibrant colors to bring a fun design for the children |
| 3 | The application will visualize the user expressions when they're doing an exercise in the app and depending on the expression (stress, confusion, happiness) the difficulty of the exercises will change |
| 4 | The application needs enough storage for it to work correctly in the device |

### 3.2 Possible Usage Scenarios

Figure 2 describes the 4 possible usage scenarios. The first two correspond to the usage of reduce screens such as Smartphones and Tablets. The third configuration contemplates the use of an interactive table. Finally, the fourth configuration foresees a use of a wall screen. These scenarios are described below.

**Configuration 1: Using a Smartphone/Tablet.** The application when its used on a cell phone allows individualized learning, that is, the user can review the topics and be seeing examples at a low level of complexity because he is only learning.

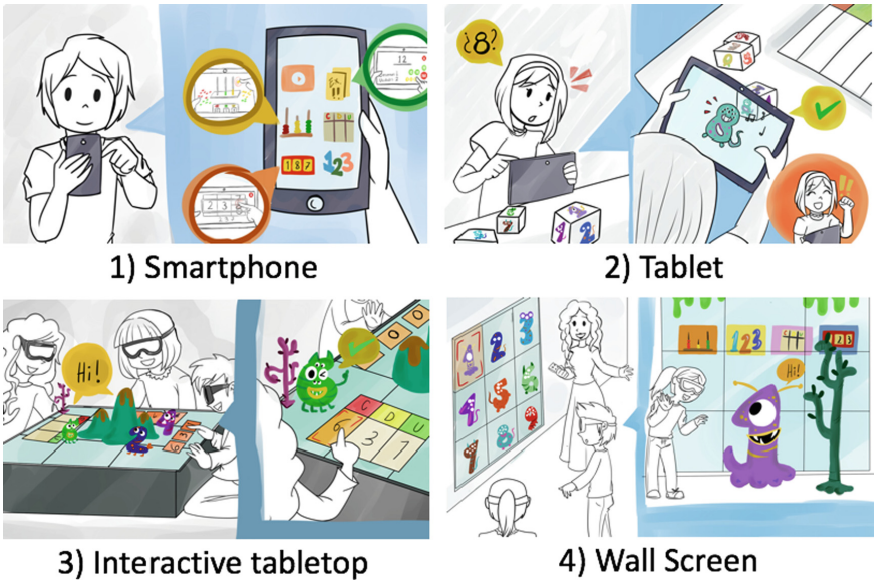


**Fig. 2.** Usage scenarios of Ar-Math.

**Configuration 2: Using an Interactive Tabletop.** In this case the learning that is desired to achieve is more advanced since a didactic material will be used that allows to live the learning, with the interactive tables, it is proposed that the exchange section can have a more sophisticated interaction since it emits sounds if they were resolved right or wrong.

**Configuration 3: Using a Wall Screen.** This modality of the application is designed in a collaborative learning, that is, the entire group of users can be doing the exercises and the teacher is the one who directs the activity as well as choosing the complexity of the exercises.

### 3.3 The Architecture

AR-Math is an interactive application based on a video game engine such as Unity version 2019.2.8, in which the user interfaces are shown in next section. Figure 3 presents the architecture of Ar-Math. The user connects to the lessons to learn the numbers and this he does with the Augmented Reality technique either using a cell phone an AR viewfinder or lenses.

AR-Math contains a series of exercises through games to learn the positional value of the number and this is done with programming in c(sharp). The exercises are connected with an artificial intelligence module with which through the recognition of images, it allows the participant's emotions to be identified in order to increase or decrease the complexity of the games.

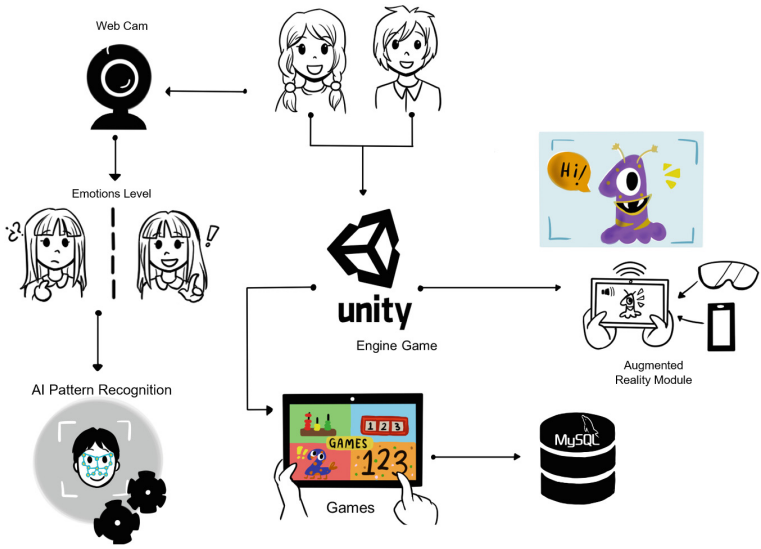


**Fig. 3.** The architecture of Ar-Math.

AR-Math architecture supports tool development with a development environment, such as Unity[1] or ThreeJS[2]. It also must support software for 3D modeling, and software that allows the development of Augmented Reality such as Vuforia[3] or Zappar[4] markers. For the capture and inference of emotions some computer vision tools defined in python will be used.

[1] https://unity.com/.
[2] https://threejs.org/.
[3] https://developer.vuforia.com/.
[4] https://www.zappar.com/.

## 4 The Tool

The Ar-Math prototype was developed considering software and hardware.

**Software:**

- Unity version 2019.2.8
- C sharp Language
- Artificial Intelligence Algorithms for Image Recognition in Python

**Hardware:**

- Webcam
- Smartphones
- Augmented Reality Viewer

Below is the image and description of some interfaces that were made based on the functionalities presented in the previous section.

### 4.1 The Main Menu User Interface

Figure 4 describes the main menu of Ar-Math. This user interface allows the user to select one of the three options offered by the application: (1) numbers; (2) games and (3) exchanges. It also includes a credits section and exit.

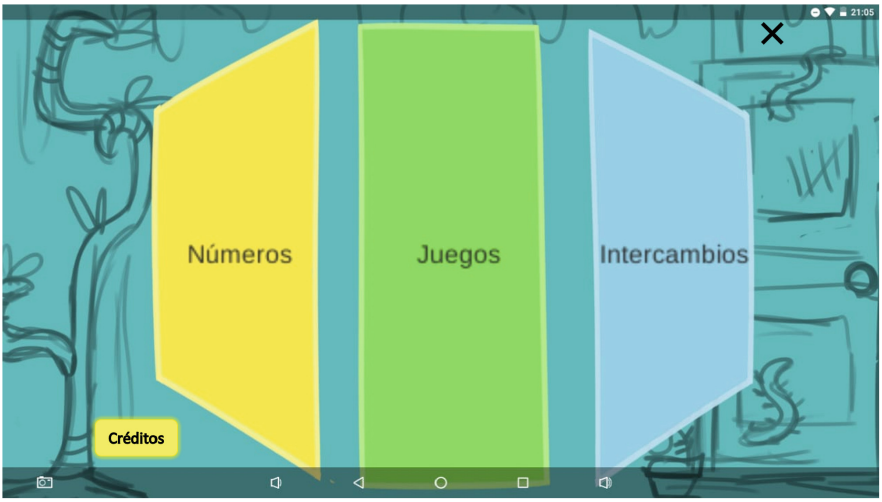


**Fig. 4.** The main menu of Ar-Math.

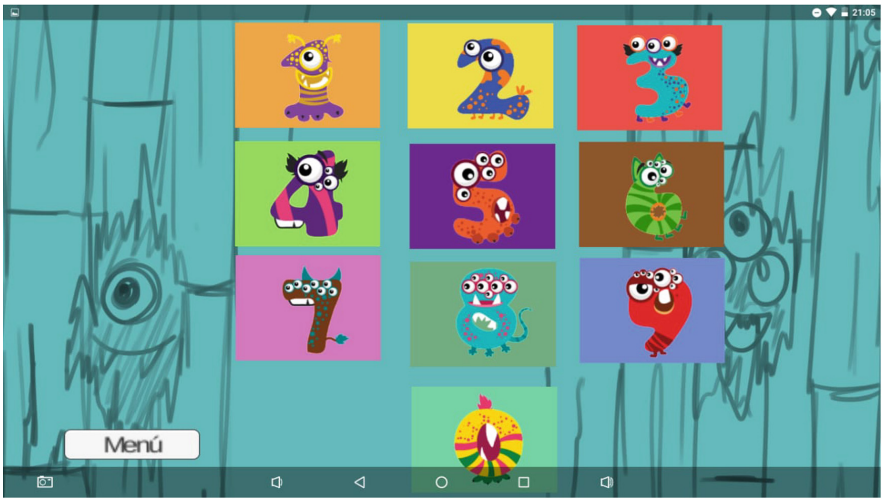


**Fig. 5.** The number user interface of Ar-Math.

### 4.2 The User Interface for Displaying Numbers Using Augmented Reality

Figure 5 shows the user interface for displaying numbers using Augmented Reality. It allows the user to interact with the augmented reality module using the viewfinder, lenses or smartphone. The user must see a 3-dimensional animation of the selected number. Note that each number represents a character which has the number of eyes associated with the number it represents.

Figure 6 shows an example of how the 3D models were made on Blender[5], because of compatibility with Unity Framework. We can see that the model needs to be as similar as the marker as possible, as shown in the example in Fig. 7. In Unity, each number is link with the corresponding model.

### 4.3 The User Interface to Play

Figure 8 describes the user interface to play the first game. It allows to the user to choose several games, among them that a character collects coins passed from units, tens to hundreds. This image shows one of the games in the application in which one of the monsters collects coins to move from units to tens and finally hundreds. It is a collection game. The coins will be scattered across the stage. The user must collect the most coins.

Thought the use of animation and augmented reality, numbers could seems "happy" if the user is doing the activity correctly and "sad" if they are wrong. So, kids will be motivated through the game into developing mathematical skills. In order to experience Augmented Reality user just have to place the camera in front of any marker as shown in Fig. 6.

[5] https://www.blender.org/.

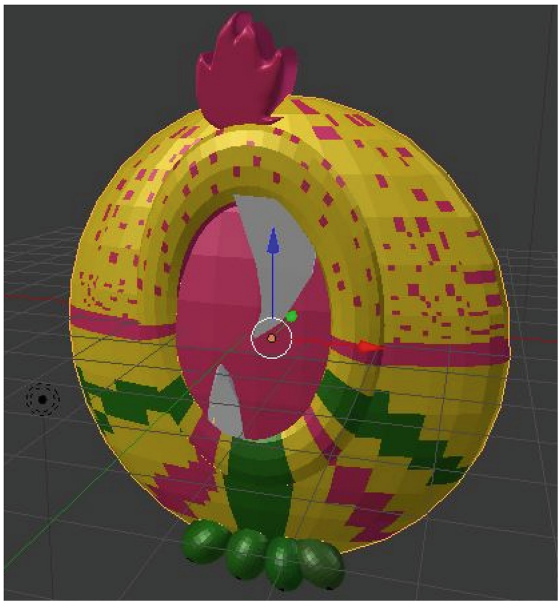

**Fig. 6.** The 3D Zero model.


**Fig. 7.** Augmented reality experience.

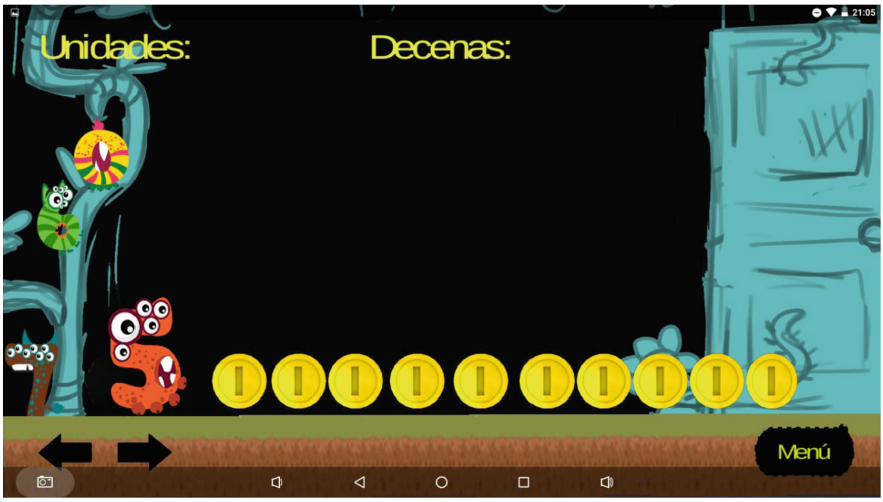


**Fig. 8.** The game user interface of Ar-Math.


**Fig. 9.** The odometer game user interface of Ar-Math.

Another game is the odometer in which a quantity is shown to the user. It must write the number that defines the position using the three available options (See Fig. 9). Both games incorporate an incentive sound for each correct answer as well as for each incorrect answer.

### 4.4 The User Interface for Exchanges

Figure 10 shows the user interface for exchanges. In this interface the user can represent the quantities that are presented on the screen. That is, the user represents quantities in the abacus making exchanges with the tens and hundreds units.

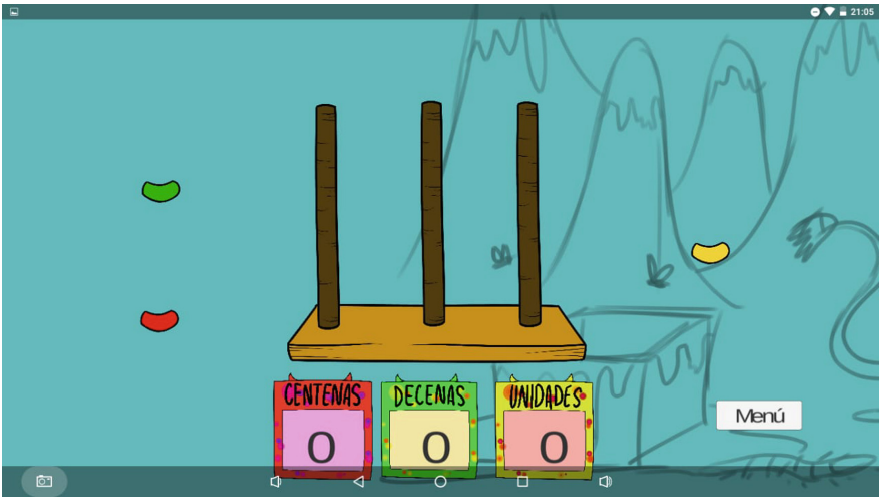


**Fig. 10.** The abacus game user interface of Ar-Math.

## 5 Benefits and Shortcomings

The educational model in Mexico, will be one of the benefits of developing this application, a serious game will helps the learning of the topic of positional value for elementary school children, working as an additional material to have the books allow autonomy in the child for learn. The results of the application can be a point of reference to propose guidelines and recommendations on the learning of positional value at the international environment. Likewise, the execution of the project can derive future investigations in other aspects of the learning of mathematics in elementary education levels.

Have a tool that serves as didactic material for learning the topic of place value; demonstrate the use of artificial intelligence in educational applications; provide a comfortable learning space for the user without feeling pressured.

The implementation of Ar-Math allow the generation of employment because it will require the involvement of multidisciplinary teams, among which we can mention educators, designers, multimedia specialists, psychologists, programmers and researchers. Likewise, it is expected to strengthen collaboration ties in different academic and industrial institutions that wish to deep in this topic.

Finally, all the knowledge generated during the execution of this project can be included in new training courses for students in the institutions owners of the project.

The technological tools to be used and the Artificial Intelligence strategies to be implemented, are computational strategies that are acquiring a lot of boom so they become an opportunity to grow the functionalities of the project.

Among the most important techniques of artificial intelligence, is Computer Vision, which is a technique focused on computers can extract information from images, offering solutions to real-world problems. Companies use it since it can help increase production and reduce manufacturing costs. Likewise, the computer vision allows to inspect the production process without fatigue or distractions that are trigger factors of human errors.

Computer vision, serious games and mathematics specifically speaking the positional value of numbers, are issues that have not been implemented for the development of applications. By doing a review on the Internet, there are several alternatives for managing the learning of mathematics, but not a serious game of augmented reality that allows the construction of learning by the user in this particular topic. That is why they will be applied in the proof of concept of this project.

### 5.1 An Innovative Tool

**Innovation Elements of the Project with Respect to the Existing One.** There are currently a wide variety of industrial and research applications aimed at facilitating and also improving mathematics learning, some are not based on any educational model, which is applied in this project. The technique of computer vision applied in a serious game that includes Augmented Reality, has not been applied very frequently. One of the most important features for this serious game is the capture and inference of emotions in order to generate a more optimal learning space and confidence to users.

**Level of Impact of the Innovation (Economic, Social, Environmental, Scientific, etc.** The impact generated by this project has a social impact, since the serious game with augmented reality and inference and inference of emotions, provides support to the second grade teacher to generate a better learning environment, in turn contributes to have children with less frustration when learning about the subject since they have a system that generates a comfortable space for learning and that understands it according to their own scope. It will also have a technological impact since in a serious game various technologies will be implemented, including the Artificial Intelligence itself, which is gaining popularity in ordinary applications today.

### 5.2 Limitations

Ar-Math, is part of the multimedia area and aims to test concepts using Augmented Reality technology to learn the subject “positional value”. Having suc-

cess in the proof of concept results the subject can be extended to any other. The restrictions will be mainly on the use of the tools, since it will be made use of trial versions of them for the Augmented Reality. However, if the solution obtained is to be marketed in the future, it will be necessary to acquire the licenses such as Vuforia or the Zappar markers.

## 6 Conclusion and Future Work

In this article we have detailed Ar-Math a serious game developed on the basis of technological principles such as Augmented Reality and Intelligent Algorithms for learning of the topic of positional value for elementary school children. The tool is an innovative mechanism focused on the education of children, in which they seek to understand the operation of the units, tens and hundreds. Ar-Math was conceived from a list of functional and non functional requirements.

As we have seen in the manuscript, Ar-Math allows young children to learn about place value using augmented reality markers as the main component. The markers must be placed in the correct position so that they can form the required number.

We consider conducting usability experiments in real conditions that involve children and teachers. The results will be used to look for new perspectives and evaluate the deficiencies and the performance of the tool. From them we could define new research. Finally, we plan to explore other possibilities of supporting learning activities of positional value. We plan to incorporate the use of tangible objects, such as: cubes to the existing application. This will allow to support other types of interactions where we can study in the participants aspects such as: participation, collaboration, leadership, respect for time and especially the learning of positional value.

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