ARMat: When Math is a Game

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***Abstract*—Mathematics are fundamental to the intellectual development of children, since through them they acquire skills such as logic, reasoning, critical thinking and abstraction. They are traditionally associated with something boring, complicated and said to be for intelligent students or that there are those who are not made for them. However, the problem lies in the way Math is taught. It is proven that practicing through games and activities outside of pencil and paper make children being more attentive and enthusiastic and allows the teacher to take them to a higher level, where they gain confidence as they improve their results. With this idea in mind, ARMat, an application based on augmented reality, has been developed to work the operations of addition, subtraction, multiplication and division with children of 6 years of elementary school. By comparing the performance of students who have carried out the operations using the traditional methodology against those who have used ARMat, it is evident that the latter obtain better results both in the number of hits and in the time taken to solve them.**

Keywords— math, augmented reality, STEM, elementary school, game.

I. Introduction

The importance of mathematics lies in that it is fundamental in the development of logic, reasoning, thought, criticism and abstraction. However, among the youngest has been the subject, by excellence, most hated or feared. Today the popularity of the STEM proposal *(Science, Technology, Engineering, Math)* that emerged in 2009 with the idea of promoting vocations to science and technology, has highlighted the need to make mathematics much more attractive, detaching it from the way it is taught, typically based on learning the concepts in a systematic way and then operating from them.

With the present work, it is hoped, on the one hand, to contribute to ease this need through the use of ARMat, an application based on augmented reality, whose objective is to allow children of 6 years of Primary Education to work the basic operations of sum, subtraction, multiplication and division, and on the other hand, to add to current literature by examining the motivation and performance of students during the conduct of mathematical operations by using such an application. To this end, the research questions posed are: *(i)* What impact does the use of AR have on students' mathematical performance? and *(ii)* Does the motivation of students increase when solving mathematical operations with AR?

After this first section, the article is structured as follows: Section *II Context*, describes the context that frames the present work, offering a brief description of the methods for teaching mathematics, the main initiatives promoting STEM studies and the use of AR to support STEM learning. Section *III ARMat* describes the interface and operation of the application. Section *IV Methodology* explains how the case study has been conducted. In section *V Results*, the results obtained are analyzed. In section *VI Discussion*, a brief discussion is presented on the role of AR as a technological medium for improving student motivation and performance. Finally, in section *VII Conclusions*, answers are given to the research questions initially raised.

II. Research Context

The research context within which this work is framed is described below.

A. Methods for teaching mathematics.

With the aim of changing the rigid teaching methods of mathematics, in recent years a wide variety of methods have emerged that are having great success because of their open and practical character, some of them are: *(i)* ABN Method (Algorithm Based on Number) [1] through which the student verifies for himself the multiple solutions of a problem and visually understands the operations that he carries out, advancing in his understanding according to his level of domain, by putting into practice the theory; *(ii)* CCSS Method (*Common Core State Standard*) [2], whose objective is for students to achieve a common minimum knowledge and to learn to reason abstractly to solve problems, going beyond their mechanical resolution and identifying conceptually different ways of representing them; *(iii)* Singapore Method [3], with which the student learns to solve problems from their relationship with everyday objects in order to carry out simple problems, to draw these concepts using blocks that represent numerical values and to make abstract representations such as numbers or symbols. With this, the student internalizes each detail in a practical way and understands the reason for each operation; *(iv)* Jump Math Method [4], based on the guided discovery with which the child discovers the things when solving the challenges presented to him; *(v)* Kumon Method [5], encourages self-contained learning, based on the use of carefully crafted worksheets, which teach pupils to find the answer to the problems posed themselves.

B. Initiatives to promote STEM studies

To respond to the challenges faced by teachers such as: maintaining student interest, incorporating technologies in the classroom and preparing them to live and work in a constantly evolving digital society, the European Commission subsidizes initiatives aimed at promoting the attractiveness of science education and careers under the slogan "science for and by society", in order to tackle competition gaps, through initiatives such as Scientix and STEM Alliance.

At the state level, the Ministry of Education and Professional Training promotes initiatives such as women in the STEAM world and regional programs such as Inspira STEAM, STEMadrid and Plan STEMCat. Also, from the private sector are initiatives such as the STEM lessons for educators offered by Microsoft Stembyme or the STEMNet collaborative platform of the Telefónica Foundation. [6].

The interest of the STEM world is such that the number of publications in the literature review on the subject has increased dramatically in the last ten years [7], encouraging the emergence of magazines with their own professional identity, as is the case with *International Journal of STEM Education.*

C. *Augmented Reality in the Teaching and Learning of Mathematics*

Technological advances and access to mobile devices have increased the popularity of Augmented Reality (AR), particularly in the educational context, where teachers can provide access to digital content and extend learning in a three-dimensional space.

Literature shows evidence of current state of use of AR for STEM learning [8] and the benefits of its use in the teaching of mathematics, through which a more effective and in-depth understanding of concepts is fostered and motivation is increased [9], [10]. Similarly, several authors point out that AR is aligned with effective educational practices that manifest themselves in five concrete ways: *(i)* commitment to learning, *(ii)* immersion and presence in the contents, *(iii)* location of content in a location or context, *(iv)* content authentication and *(v)* community building [9]. Today, interaction with AR does not require the use of markers such as QR codes that act as mediators between user and content, but can be achieved by recognizing a page as a whole, identifying its content as interactive, being able to visualize immediately the corresponding 3D object. However, some studies in which students have used markers show that it encourages collaborative work and problem solving [11], facilitates the understanding of mathematical concepts because it allows for better visualization and interaction by manipulating augmented objects [12], [13], [14] and helps to acquire basic skills in science and technology, as well as digital skills [15] [16].

III. ARMAT

ARMat is an AR-based application that allows working with addition, subtraction, multiplication and division operations. Its design includes typical components of game mechanics, such as the use of unlocks, scoring and sorting [17]. Once the application is accessed, the student can select between three different options corresponding to the available game modes: "Tests", "Evaluation" and "Minigame", being able to return to the previous screen from the option "Back".

By selecting the "Testing" option the student can choose the type of test to be performed from the four available (addition, subtraction, multiplication and division).

Once you have selected the type of test or evaluation, you can access the screen of levels ranging from 1 to 4, with 1 being the least difficult and 4 the most difficult. The levels differ both in the time available to answer the questions and overcome the level, and in the difficulty of the operation to be carried out. It is recommended to work each level as follows:

- Level 1: Courses from 1st to 6th grade.
- Level 2: Courses from 2nd to 6th grade.
- Level 3: Courses from 3rd to 6th grade.
- Level 4: Courses from 4th to 6th grade.

After selecting the level, you want to play at, the screen of Figure 1 which will appear will appear at the top with a bar showing the remaining time (right, in this case 71) and the number of hits (left, in this case 0) achieved by the student. In order for the questions to be answered, the student must focus the operation marker with the rear camera of the mobile device and then, to answer, he must point again to the corresponding marker. Each possible answer (there are only four options) is identified with a color (green, blue, orange and fuchsia), so that the student must select the color marker of the correct answer. For example, in Figure 1, the marker that corresponds to the correct answer will be the blue one.

Figure 1. Game screen and response selection markers

Once the student has indicated his answer, an image will appear with a "smiling face" and a green background, accompanied by a sound if the student's answer is correct. Otherwise a "sad face" will appear with a red background and another sound, as shown in Figure 2.

Figure 2. Correct answer display (left) and incorrect answer display (right)

The student will have passed the level by correctly answering the ten questions asked. In case time ends without the student being able to answer all ten questions, the "Game Over" in which the student will be able to observe the score obtained and the record reached. From this screen the student can return to the beginning of the application or play again.

If the score reached is less than 5, a screen will be displayed with a message indicating to the student that he/she needs a series of reinforcements, in the operation the student was performing.

Finally, as a stimulus, the app has an option called "Minigame" which is unlocked when the student hits 15 questions in the "Review" part and which consists of finding a hidden character in the place where the student is. To do this the student will have to move around the site, while moving the mobile device in different directions, as shown in Figure 3, where it can be observed that the student has found the character and therefore must click on it and it will appear in another position within the site.

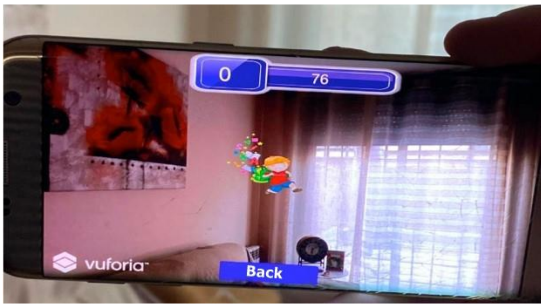

Figure 3. ARMat Minigame

When the time runs out, the "Game Over" screen will appear that will show the score obtained.

IV. Methodology

The methodology applied in the case study is described below.

A. Context and participants

The study was carried out in a private school in the Community of Madrid and a total of 60 students of 6 years old belonging to the classroom of 1st of Elementary School.

B. Experimental Design

A quasi-experimental design has been used, in which groups have been randomly assigned, forming two groups: *(i)* the control group that has used the traditional methodology (paper and pencil) and *(ii)* the experimental group that has used the ARMat application, based on AR. Both groups have had to resolve the same operations through their respective methodologies.

C. Process

Two shifts have been defined during which students had to solve ten questions consisting of addition, subtraction, multiplication and division operations, with four possible answers, being able to choose a single correct answer, all in a maximum time of 15 minutes.

Control group students completed the sheets provided by the teacher, circling the correct answer. Figure 4 shows students in the classroom performing the activity using the traditional methodology.

Figure 4. Students solving questions with the traditional method

Students from the experimental group used ARMat. To solve the operations the student had to point with the camera of the mobile device to the marker (QR code) of the color corresponding to the answer he considered correct (as explained in section III.).

In Figure 5, shows several photos of the students solving the operations using the ARMat application and the help of different indicators.

Figure 5. Students solving mathematical operations with ARMat

To obtain the indicators of the number of hits the procedure was the following: 10 questions were asked that had to be answered in 15 minutes. After observing each student, the number of hits obtained was noted. In the experimental group, this information was obtained from the bar at the top of the ARMat screen, which has an indicator that counts the number of responses that the student has answered correctly.

On the other hand, in the control group this information was obtained by correcting the sheets of paper on which the successes of each student in the proposed operations were counted.

With regard to the measurement of the time used, the indicators were obtained by using a timer, so that each time a student finished answering the 10 questions, both in the experimental group and in the control group, the timer was stopped and the time taken to solve the operations was recorded. At the end of the 15 minutes available for the test, students were instructed to stop performing the mathematical operations, both on paper and with ARMat and those who had not been able to answer the 10 questions were written down as "time exceeded".

V. Results

To evaluate the impact of ARMat's use on the students' mathematical performance, the following variables have been used: the number of correct answers or hits and the time taken to answer all the questions. Table I shows the main statistics of the results obtained regarding to the two variables for each of the groups.

As can be seen, the results obtained by the students of the experimental group are better than those of the control group, both in the number of hits, and in the time spent in answering all the questions. The next step is to determine whether these differences are statistically significant.

First, we analyze the results regarding the number of hits in each of the groups. As can be seen in Figure 6, all students in the experimental group correctly answered at least nine questions (83.3 percent answered all the questions correctly and 16.7 failed one question). Regarding the control group, 86.7 percent answered at least nine questions (66.7 percent answered all questions correctly and 20 percent failed one question), while the remaining 13.3 percent failed two or more questions.

The next step is to assess whether the improvement in the results of the experimental group is statistically significant regarding to those obtained by the control group. To do this, we first applied the Shapiro-Wilk test to confirm the assumption of data normality. For the control group a value of p = 4.7e-07, whereas for the experimental group this value was p = 1.7e-07. As in both cases $p < 0.05$, the data did not meet the normal assumption, so it was decided to use the non-parametric test of Wilcoxon. The result of this test was p = 0.099 which concludes that there is no statistically significant difference between the results obtained by both groups.

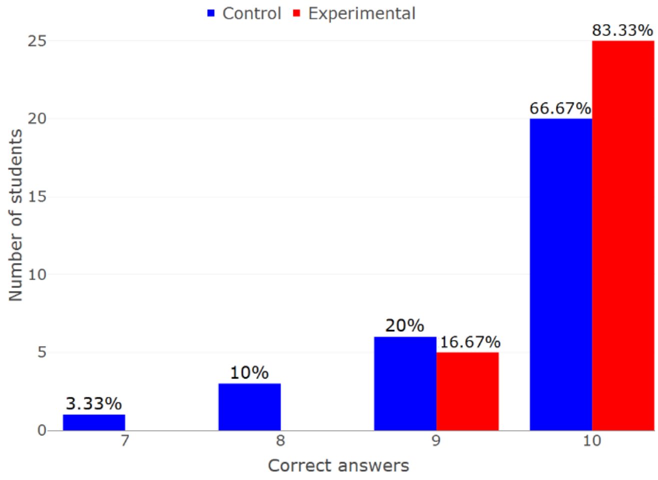

Figure 6. Number of correct answers separated by group

Looking at the box plot in Figure 7, a similar conclusion is reached with respect to the reduction of time in the experimental group.

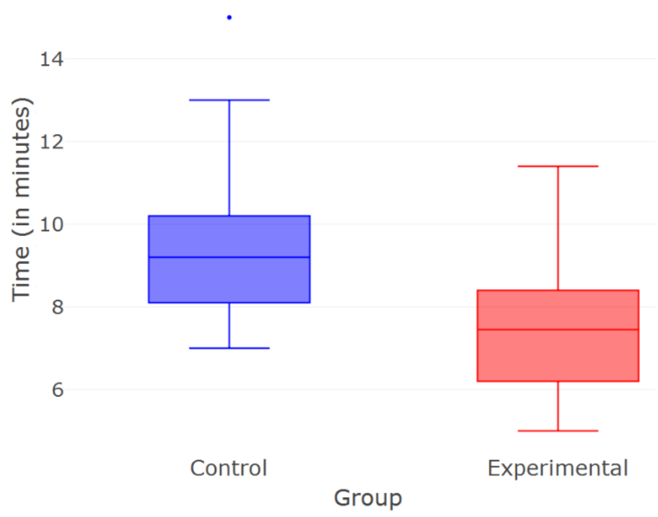

Figure 7. Time spent by students in each group to solve all mathematical operations

Now if we analyze the data of both groups regarding the time taken to solve all mathematical operations. As shown in Table I, students in the experimental group needed approximately two minutes less to solve all mathematical operations.

As you can see, 50 percent of the students in the experimental group took between 6 and 8 minutes to solve all the mathematical operations, while 50 percent of the students in the control group needed between 8 and 10 minutes.

Another noteworthy fact is that approximately 75 percent of the students in the experimental group were able to complete the test in less than 8 minutes, while 75 percent of control group students needed more than 8 minutes to solve all operations. Finally, it should be noted that in the control group there is an outlier corresponding to a student with educational reinforcement at the methodological level who failed to complete the test in the time allowed.

TABLE I. DESCRIPTIVE STATISTICS FOR EACH GROUP

Group	Minimum	Mean	Median	Maximum	Standard Deviation
Control					
Hits	7.00	10.00	9.50	10.00	0.82
Time	7.00	9.20	9.46	15.00	1.92
Experimental					
Hits	9.00	10.00	9.83	10.00	0.38
Time	5.00	7.45	7.53	11.40	1.45

To conclude this section, we must analyze if the difference observed in both groups with respect to the response time is statistically significant. After applying the Shapiro-Wilk test, it is observed that the data of the students of the experimental group follow a normal distribution (p = 0.59), while those of the control group do not comply with the assumption of normality (p = 0.016). For this reason, we decided to use the Wilcoxon test.

The result of this test confirmed that the difference between the two groups was statistically significant (p = 6.7e-07) with r = 0.52, which indicated the existence of a large effect [17], on the differences in time spent solving all mathematical operations between the students of the experimental group and the control group.

VI. Discussion

A. *Technology supports learning mathematics*

The results show that both types of conditions, (those of the control group and the experimental group), lead to overall achievement concerning to learning mathematics. While the difference lies more in the time spent on resolving operations, technology support enriches the learning experience. as students learned the concepts faster and enjoyed their classes more when AR-based instruction was included [19]. This result can be added to those studies in that it shows the effectiveness of the use of technology for the teaching of mathematics [20], [21].

B. *AR increases students' motivation*

There were no significant differences between the groups with respect to the number of hits achieved. However, the results differ in terms of the time spent by the experimental group to perform the operations, suggesting that AR may have caught the attention of the students. This result supports previous research that shows that using AR in the classroom can increase motivation [10], [11]. Possibly the fact that ARMat shows a record of successes and time, has generated a competitive spirit among students. It should be noted that at the end of the experience the students were asked their opinion. Some examples of them are: "The best math class", "I liked it a lot", "Very entertaining", "Very agile mental calculus", "We played all together", "As usual classes, but in another way cooler", "We have made the class short because we have not been bored".

C. *AR increases students' performances*

In any process of motivation two key elements are distinguished: stimulus and response. In the particular case of this study, the stimulus can be identified with the use of AR and the response would be represented in the successes obtained by the students after carrying out the operations with ARMat. Therefore, it can be said that AR acts as a tool that increases motivation and whose effect is reflected in better performance by students, as confirmed by recent studies [22].

VII. Conclusions

The aim of this study was to determine the impact that AR has on the learning and motivation of students, it is therefore time to answer the research questions posed.

What impact does the use of AR have on students' mathematical performance? The results indicate that a motivated student can better execute the tasks assigned, obtaining better results in their execution. In this specific case, it has been possible to confirm its increase in interest in solving mathematical operations, probably motivated by the novelty of the interaction offered by ARMat and the possibility of interacting with three-dimensional objects.

Does the motivation of students increase when solving mathematical operations with AR? Clearly, it has been seen that at the end of the operations, the students wanted to continue experimenting with the application. Their motivation has become palpable in the multiple opinions conveyed by them, through which they expressed their enthusiasm for having had a different class, in which they lost track of time because they were having a good time while learning how to solve mathematical operations in a more dynamic and intuitive way. In addition, unlocking the "Minigame" represented for them a challenge that they took up with great enthusiasm. Therefore, it can be argued that AR can encourage motivation, understanding and greater involvement with learning content [12].

Future work will centered on: (*i*) make improvements to the user interface, (*ii*) add sub-levels with degrees of difficulty, (*iii*) offer operations for secondary (roots, equations, polynomials, etc.), (*iv*) implement the iOS App and finally, after making the improvements carry out a new case study in order to obtain new results that officially endorse its use in schools.

With this study, we wanted to contribute in the STEM formation, which must start from primary school and even from younger ages. This training is characterized by practical learning, through which students have learned to solve problems, to work as a team, to arouse their curiosity, their imagination, their thinking and to enrich their digital competence.

They have also found that it is possible to learn in another way, that technology can be their ally in the classroom and that they are facing a world that is moving towards digitalization, in which the most demanded profiles are the technological ones. "The ideal would be to come to consider technology as the global language of the future, since digitalization is and will be very present in everyone's day-to-day life and will have a strong impact on both the personal and professional development of students" [23].

Acknowledgements

This work has been co-financed by the iProg Project: New generation of programming learning tools with emerging interactive technologies (ref. TIN2015-66731-C2-1-R) of the Ministry of Economy and Competitiveness (State Program for Research, Development and Innovation Oriented to the Challenges of Society, R&D&I Projects, within the framework of the State Plan for Scientific and Technical Research and Innovation 2013-2016).

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