Voluminis: An Augmented Reality Mobile System in Geometry Affording Competence to Evaluating Math Comprehension

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Abstract. The spatial competence for learning three-dimensional objects in the geometry course makes Augmented Reality a perfect ally, due to its popularity among children allowing them to experience more realistic learning. Also, the use of augmented reality allows to improve the interactive and spatial skills with three-dimensional objects. A mobile interactive augmented reality system with 3D models was developed for the teaching of geometry, allowing the teacher to obtain real-time results of the student's spatial and mathematical competence in a real-world environment. In the mobile system, a playful environment capable of visualizing geometric figures (Cube, Rectangular Prism, Triangular Prism, Pyramid, Cone, Cylinder and Sphere), and formulas to calculate its volume are proposed. After learning the formulas, the student must continue with the game and obtain the highest score without visualizing the formulas in such a way that in a competitive environment they can experience more realistic and beneficial learning to improve their spatial competence. The students evaluated are in the primary level (sixth grade) of two classrooms in the city of Arequipa, Peru, enrolled in a one-week course (4 h a week) entitled "Mathematical Logic", and divided into a experimental group (they used Voluminis) and a control group (traditional methodology). A performance test (post-test) and a satisfaction questionnaire were used. In addition, a pre-test to both groups to determine the same level of knowledge about spatial geometry. The results revealed a positive impact on performance, greater academic motivation of students and above all increased competition among students in the Voluminis game. Thanks to the results in real time the professor observed the learning difficulties of the students and obtained the immediate qualifications of the space competition. Voluminis can be part of the qualified evaluation of the course, because it provides the evolution of each student in the area of geometry. It also helps to strengthen space skills thanks to the competition activities that occur in the game.

Keywords: Mobile Augmented Reality · Mathematics learning · Solid geometry · System learning

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1 Introduction

Augmented Reality (AR) allows you to show the user virtual objects overlaid in the real environment [7]. Besides, AR offers a different way of interacting with information, in such a way that it improves the user experience during learning. Therefore, it is applied in subjects such as physics, chemistry, geography and mathematics [12]. Also, Mobile Augmented Reality (MAR) appears as an attractive technology that provides entertainment, space capacity development, and portability.

The use of mobile devices in AR facilitates teaching and learning, as they are widely used among young people for their novelty [1]. In recent years, AR-based mobile games such as Pokemon Go, Jurassic World Alive or Harry Potter: Wizards Unite are popular with children and young people. That is why, using AR, students will obtain content more easily from AR applications, than in a traditional classroom [13]. Moreover, the activities used in mobile augmented reality (MAR) applications can be reviewed anywhere else. MAR provides the opportunity to build independent experiences based on prior knowledge of the respective subject [1].

In this study, two applications were designed and developed: a MAR video game for primary school students, whose purpose is to help explain and practice spatial geometry exercises (such as the volume of an object); Contribute to learning, understanding geometric figures in three dimensions and mainly competition. And an application for the mentor, to monitor student results in real-time; In addition to analyzing the state in which it is. With the help of the augmented reality mobile application, the participants learned the concepts of calculating the volume of solid geometries such as a cube or a prism. Students can also interact with the geometrical figures through the mobile device screen, object scaling is also implemented. The objective is to provide students with a complementary tool and test the effectiveness and influence of this video game in a traditional geometry teaching classroom.

2 Literature Review

2.1 Geometric Theory

Geometry is an important topic of mathematics that serves as a major base for exploring space and form, in turn, is important for academic success and professional, PISA 2021 (The Programme for International Student Assessment)[1].

In [6], the use of technology in the teaching of geometry in children is proposed for the best benefit of curiosity, even in other projected investigations the use of AR in geometry, in the way that you can project and interact with 3D objects. For example, [10] introduces geometry with the use of puzzles for 6-year-olds. On the other hand, [3] proposes that the use of AR helps students visualize the design and construction of edits including geometric information. Thus it can be affirmed that geometry is very important in personal development.

[1] https://pisa.e-wd.org/.

2.2 Gamification

Gamification helps make a system enjoyable, and also increases interaction. In many serious games, there are several examples of gamification such as point system, collection systems, time and track systems [17]. For that reason, gamification is being used in teaching methods, to increase motivation, teamwork, self-knowledge, and retention of knowledge. In turn, it provides information to the teacher. In addition to the new tools, they assume an important commitment with the students, who increasingly acquire greater knowledge about technology, especially video games [15].

2.3 Augmented Reality and Education

Virtual reality and augmented reality are very popular due to their high quality and accessibility [11]. AR games incorporate students into the learning process, so that students finish all the objectives of the game, even if they suffer from any difficulty such as Attention-deficit/hyperactivity disorder (ADHD) [14]. Similarly, in [2] where they found that students with difficulties learning math (Dyscalculia), showed interest, motivation, and improvements in mathematical reasoning. On the other hand, it is necessary to have a multimodal presence (visual, auditory and tactile, among others) in MAR to recover accurate data and significant information effectively [8].

In a nutshell, MAR video games have a positive effect on students in the math course. As for spatial geometry, the need for a good spatial capacity in students, allows MAR to be an appropriate technology in the course of mathematics since it helps in the understanding of three-dimensional objects.

According to related research, AR-based learning can increase students' motivation to learn [4,5,9,16].

It is also able to improve student performance with the right resources and at the right time [9].

3 Designing and Developing a MAR System

This section describes the design and development of the Voluminis system, which is a set of applications, which are installed in the Android 7.0 or higher operating system to meet the needs of the ARCore[2]. The applications were developed in the Unity[3] game engine with the programming language C#. In addition, a real-time database of Firebase[4] was used. The core of the system is mainly using ARCore to detect and recognize surfaces and lift interactive 3D objects on the plane. This system consists of two main modules (see Fig. 1), which includes the administrator or teacher module and the student module. It should be noted that privacy and data protection are guaranteed. These modules are described in detail in the next section.

[2] https://developers.google.com/ar.
[3] https://unity.com/.
[4] https://firebase.google.com/.

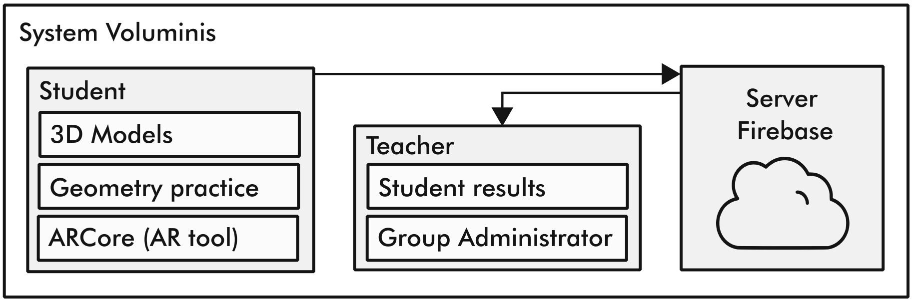

Fig. 1. System architecture

3.1 Student Module

This module represents a game that provides students with a series of exercises, as shown in Fig. 2. The session begins with an account and a group code that will allow us to store the score of each of the students and will encourage competition among the students. The number of exercises of each geometric figure is shown in Table 1. For each successful exercise, the student gets 10 points, for each wrong answer they lose 1 point and if they want to remember and get the formula to solve the exercise, they lose 5 points. The student who hits all the exercises without losing points gets a maximum of 100 points. Once the game is over, the score restarts and starts again.

Figure 3 shows one of the exercises, each exercise has three alternatives of which one is correct and the other two are incorrect. Measurements of geometric figures and alternative solutions of exercise are randomly changed for each attempt made.

Table 1. Number of exercises per spatial geometric figure

Object used	Number of exercises
Cube	1
Rectangular prism	2
Triangular prism	2
Pyramid	2
Cylinder	1
Cone	1
Sphere	1

3.2 Administrator or Teacher Module

This module is an administrator application, which allows the teacher to create and delete groups of games. Also, you can visualize the results of each student's exercise with their respective real-time attempts. So, the teacher can identify students with fewer skills to reinforce the subject in subsequent classes. Finished the game session the teacher can export the results in a spreadsheet, with this will see the score of each student with their respective name.

Fig. 2. Game levels: The 10 levels of the game on a journey from the countryside to the top of the volcano (Misti, Arequipa, Peru), from the easiest figure (cube) to the hardest figure (sphere).

An example of the list of names and scores of the participants with the status of their achievement is shown in Fig. 4. Where, gold means that it was perfect (10 points), red that was achieved (0 to 9 points) and lead that failed to learn.

4 Method

4.1 Research Design

As a hypothesis, it is established that by integrating applications of augmented reality on spatial geometry, a significant contribution will be made to the acquisition of mathematical skills on spatial geometry in elementary students.

The study is carried out through an experimental type design with different modalities, pre-test and post-test measures in the two groups (experimental and control), as seen in Fig. 5. Students are divided into two groups: experimental group (E.G.), whose members will use the application; and the control group (C.G.), formed by the subjects that will use traditional activities (practice exercises with sheet and pencil). Both groups were randomly selected. Following the methodological criteria of this type of research design, measures of each individual are collected, before and after the intervention.

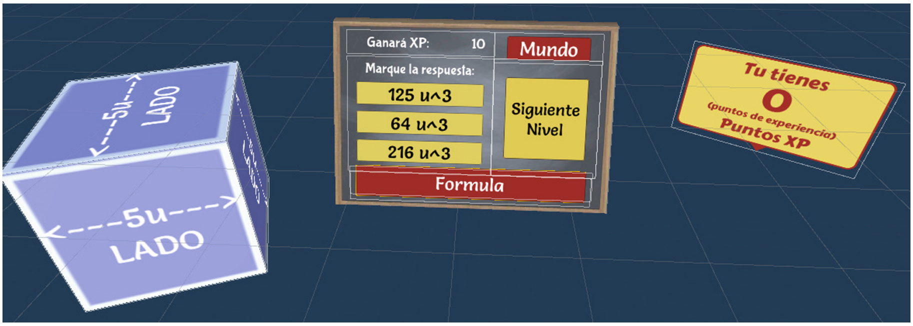

Fig. 3. Game exercise: geometric figure, exercise chart with points to be earned, alternatives, next level button, formula button, return to main menu button (World) and total points earned.

4.2 Variables

The training program about solving exercises spatial geometry is the independent variable. The dependent variable is defined as the mathematical capabilities of students on spatial geometry.

4.3 Participants

In this study involved students from the Educational Institution Señor de Huanca CIRCA (Arequipa-Peru), the sixth grade of primary school was intervened, the ages of the students range between 10 and 12 years. Before carrying out the study, students acquired prior knowledge of basic geometry with traditional methodology, this class was taught by the teacher in charge. A sample was taken randomly ($n = 11$, of which 5 are boys and 6 are girls). After the explanation of the intervention, this first group known experimental group identified the application during a regular math class session, while the other group ($n = 10$, of which 5 are boys and 5 are girls), using the traditional methodology of the students in a practice with exercises during the same time this group was called: control group. Girls represent 54% of the subjects of the experimental group and 50% of the control group.

4.4 Procedure

Figure 5 shows the experimental procedure. The research was structured based on three stages: The first stage involves the measurement of the dependent variable (pre-test) with a duration of 10 min; in the second stage, the intervention is developed with the application of the game and a duration of 25 min; and in the third stage, the evaluation test (post-test) is repeated with a duration of 10 min.

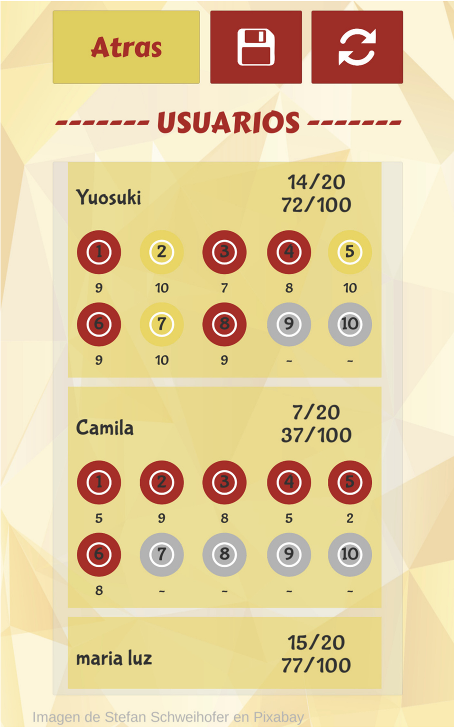

Fig. 4. Game administrator: names, scores of 100 and 20, state and score each level.

The intervention consisted of the resolution of the first 7 exercises of the application with the children of the experimental group, see Fig. 6, considering that the participants can restart the game and achieve better scores than the previous attempt, the only one Limiting is time. On the other hand, the control group focused on the resolution of 14 exercises (2 cubes, 4 rectangular prisms, 4 triangular prisms, and 4 pyramids). The application of the evaluation tests was carried out individually pre-test and post-test, to demonstrate the influence of different learning modalities on academic performance.

The pre-test consisted of 7 questions, each of which had an exercise with different measures and with different geometric figures, without placing the formulas.

4.5 Analysis of Data

To verify the influence of the Voluminis system on the acquisition of mathematical skills on spatial geometry in schoolchildren, the analysis of the results obtained from the pre-test and post-test was carried out.

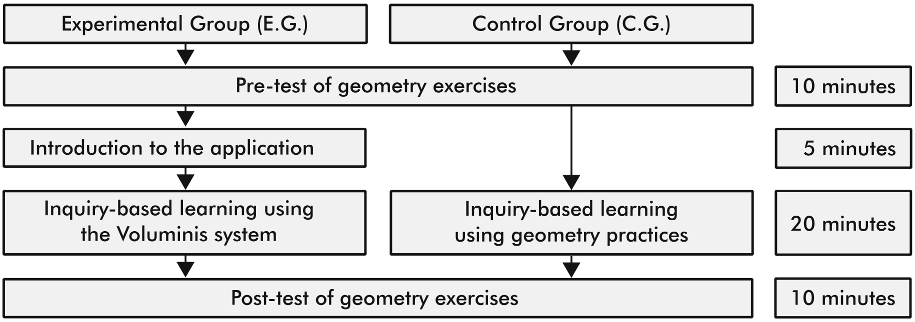

Fig. 5. Experimental procedure

(a) (b)

Fig. 6. Students using the application (a) Outside the classroom (b) Inside the classroom

First, two normality studies were carried out using the pre-test and post-test, to compare both groups. For this study, the Shapiro-Wilk normality test was used. The use of this test is recommended when the study is performed on a sample of fewer than 30 individuals, as in this case. In the statistical analyses that are carried out, <0.05 is established as a critical value. Subsequently, the normality study of the pre-test and post-test sample based on the differences in scores was carried out, the Shapiro-Wilk normality test was also used. Similarly, this data does not follow a normal distribution.

From the above, we can deduce that we must use non-parametric contrast tests such as Mann-Whitney U and Wilcoxon W.

5 Results

The data obtained in the pre-test show that the groups (experimental and control) do not show significant differences ($p > 0.05$), as can be seen in Table 2. Also, the data obtained in the post-test shows that there are no significant differences ($p > 0.05$) between the experimental group and the control group, as can be seen in Table 3. To know the incidence of the dependent variable, it was decided to analyze the difference between the pre-test scores and those obtained in the post-test, for the two experimental and control groups (Table 4).

The difference between post-test and pre-test shows that there are significant differences ($p < 0.05$), with this it is interpreted that the score (post-test) of students after traditional practices and the Voluminis system differ from the initial score (pre-test).

Some anecdotes that arose when applying Voluminis were the following: At the stage of the introduction to publicize how the Voluminis application was going to be done, some of the students were already interacting with the exercises of the game, being something intuitive for them. On the other hand, during the session with Voluminis some students used paper and pencil to solve the exercises. Regarding the aspect of competing with their peers, they wondered about the score they were getting to improve. Additionally, somebody participants were trying to pass the exercises randomly marking the answer. Also, some had difficulties in recognizing the surfaces required by the ARCore tool to lift the game.

At the end of the session, the students showed interest in the game, they are motivated, wished they had more time with the application and asked if more applications had been made to download them in their homes and that they could practice the knowledge acquired in the classroom.

Table 2. Differences in the pre-test between experimental and control groups (Mann-Whitney test)

	Points
U de Mann-Whitney	44,000
W de Wilcoxon	99,000
Z	−,976
Sig. significance (bilateral)	,329

Table 3. Differences in the post-test between experimental and control groups (Mann-Whitney test)

	Points
U de Mann-Whitney	32,000
W de Wilcoxon	98,000
Z	−1,948
Sig. significance (bilateral)	,051

Table 4. Analysis of the differences between post-test and pre-test (Wilcoxon test)

	PostTest - PreTest
Z	−3,366
Asymptotic significance (bilateral)	,001

6 Conclusion and Future Works

The results of the control group and the experimental group showed similar behavior. It is suggested that this way of acting is since the two methodologies manage to impart knowledge, and the student manages to capture it, however, the methodology with the use of technology leaves more motivated the student, wanting to continue learning and gaining more knowledge.

This study demonstrates that it is possible to increase math skills in geometry, being able to test the hypothesis. Considering that it had similar results to the traditional methodology.

Thanks to the use of MAR, great interest and acceptance were obtained by the students during the game. The way of transmitting the concept of three-dimensional space, in comparison with two-dimensional drawings, promoted its acceptance. About the use of augmented reality, it can help students to have more interest in mathematics. About the competition, it can be an essential motivator in a group of participants in the use of educational games.

In the future, it could be integrated with more interaction methods such as rotation and animations. On the other hand, to increase the interaction time in classes and at home, it should be considered that the number of students who have a mobile device with sufficient characteristics to exercise MAR applications is low. Finally, you could introduce composite geometric models such as a sphere and a cone, achieving a figure in the shape of an ice cream ball on top of an inverted cone.

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