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Design of an Augmented Reality Application for Educational Content Creation

Diseño de una aplicación con realidad aumentada en la creación de contenidos educativos

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Abstract: The present study describes the development of an interactive application based on Augmented Reality with educational content to be used as a didactic resource at different times of a geometry class in elementary school. Initially, the subject of the class is chosen for the prototype content, the characteristics for the application design and the definition of its functional and non-functional requirements are determined, and the Augmented Reality content development tools are selected. Then the prototype is developed, which includes three scenarios: the first, allows the projection of geometric solids in Augmented Reality using image markers. The second scenario allows to calculate the volume of the geometric solids given their input data according to the respective volume formula and the third scenario is about a set of questions related to the subject that yields a final score according to the correct answers. Once the prototype has been implemented in the different class sessions, an evaluation is carried out by the students regarding its usability and functionality.

Keywords: Augmented reality, education, usability, prototype, SUM.

Resumen: El presente estudio describe el desarrollo de una aplicación interactiva basado en Realidad Aumentada con contenido educativo para ser usado como un recurso didáctico en los diferentes momentos de una clase de geometría en básica secundaria de una institución educativa oficial. Inicialmente se escoge el tema de la clase para el contenido del prototipo, se determinan las características para el diseño de la aplicación y la definición de sus requerimientos funcionales y no funcionales y se seleccionan las herramientas de desarrollo de contenidos de Realidad Aumentada. Luego se desarrolla el prototipo el cual comprende tres escenarios: el primero, permite proyectar los sólidos geométricos en Realidad Aumentada usando marcadores de imagen. El segundo escenario permite calcular el volumen de los cuerpos geométricos dados sus datos de entrada de acuerdo a la respectiva fórmula de volumen y el tercer escenario tiene que ver con un juego de preguntas referentes al tema de volumen el cual arroja un puntaje final según las respuestas acertadas. Una vez implementado el prototipo en las diferentes sesiones de la clase, se realiza una evaluación por parte de los estudiantes en cuanto a su usabilidad y funcionalidad.

Palabras clave: Realidad aumentada, educación, usabilidad, prototipo, SUM.

1. INTRODUCTION

The main objective of any educational process is to be able to guarantee that learning takes place and for this it must cause changes in the way information and knowledge are acquired [15] [1].

It is very notorious to see that the implementation of ICT in education and its growing influence contributes to the improvement of teaching-learning processes as they become a valuable resource when it comes to explaining and demonstrating the different curricular contents in the areas of knowledge by teachers, since the way of teaching and learning today is definitely not the same as in previous decades [2].

One of the possible causes of students' lack of motivation to study is the disconnect between the science being taught and the world around them and the lack of practical applications, i.e. the absence of interactions between science, technology and society [16] [3].

Mobile devices, computers, the internet have revolutionized the global education sector and have taken it to a higher level and in this sense Augmented Reality has become an emerging technology that in different areas has been successfully used to achieve organizational objectives and, specifically in the educational area, it has introduced new forms of knowledge dispersion, contributing to the metamorphosis of traditional education towards content that stimulates the student's senses, reducing the complexity of concepts [17] [4].

The realization of this project seeks to deliver a tool with educational content that incorporates Augmented Reality and that is used as an additional resource with the aim of providing the teacher with one more element in the deck of resources that can be available in the classroom. This educational content complements didactic elements in addition to the board, the marker, the book, the exercises and other activities that have been planned for the development of the class [5].

2. AUGMENTED REALITY AND EDUCATION

Augmented Reality is that additional information that is obtained from the observation of an environment, captured through the camera of a device that previously has software installed [18] [4].

Augmented Reality does not replace the real world with a virtual one, but on the contrary, it maintains the real world that the user sees complementing it with virtual information superimposed on the real one, in this way, the user never loses contact with the real world that is within reach of his sight and at the same time can interact with the superimposed virtual information. The progressive implementation of new technologies in the classroom, added to the unprecedented increase in mobile devices in the population, places Augmented Reality in a prominent position [5].

Augmented Reality can significantly improve the learning experience and has shown additional intrinsic benefits, such as improving student motivation, therefore, the creation of didactic content using Augmented Reality becomes an important resource by including it in a lesson plan for the development of the learning process and construction of new knowledge.

The educational and technological reality in the classrooms of the different academic levels in our educational system today, comes hand in hand with the incorporation of new tools that bring students closer, in a simple, playful and formative way, to the curricular content and that one of the technologies that are gaining greater momentum and importance today is Augmented Reality, which has been making its way, especially in higher education [6].

Figure 1 presents an example of Augmented Reality.

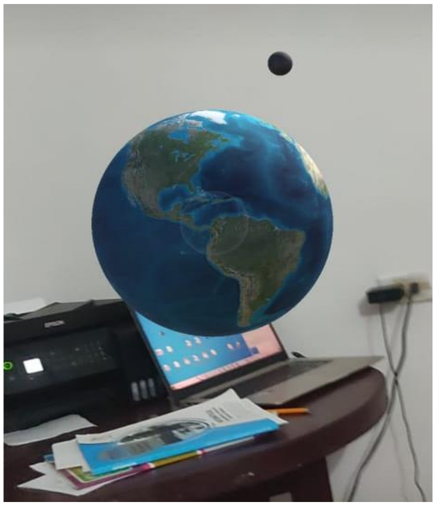

Fig. 1. *Augmented reality*
Source: *Authors.*

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3. SUM DEVELOPMENT METHODOLOGY

Among the methodologies for developing systems is the SUM methodology. SUM aims to obtain predictable results, efficiently manage project resources and risks, and achieve high productivity of the development team. SUM adapts the structure and roles of Scrum. Phases are concept, planning, elaboration, beta and closing, and throughout the process, a phase called risk management [7].

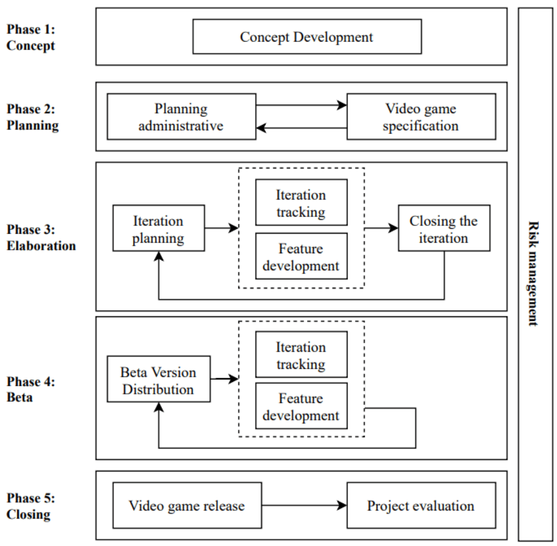

Fig. 2*. SUM Development Model*

3.1. Materials and methods

The approach is quantitative because it represents a set of processes that are sequential and evidential. Each stage precedes the next and no step can be avoided, it is rigorous to maintain the order redefined in stages.

The research is quasi-experimental, which are non-random research schemes and allow the selection of accessible and already constituted groups, in addition, it is often difficult to find groups that meet all the requirements to participate in an experiment. Consequently, to conduct quasi-experimental research correctly, it is necessary for researchers to select the type of design that will make sense of the process. In the case of this research process, a cross-sectional design is established that aims to study and compare the variables at a specific moment in a given period of time (a single moment).

3.2. Population and sample

The study population is the eighth grade (only grade) of basic secondary school students of the official rural educational institution San Juan Bautista de Chinú, Colombia, which amount to 37 students (15 girls and 22 boys) between 12 and 15 years old. This population is mostly from socioeconomic stratum 1. The main economic activities in this area are agriculture and daily work. Most of the students are children of farmers and farm caretakers. Access to ICTs in this region is deficient due to the geography of the place and the economic situation of the inhabitants.

The sampling method used in the research is non-probabilistic since it represents the entire study population that will be considered.

3.3. Instrument

For the development of this research, the social survey was chosen as a procedure. With respect to the survey, the following considerations:

3.3.1. Preparation and validation of the survey

The survey is prepared using the questionnaire instrument. The questionnaire is composed of 15 dichotomous closed questions. This measurement instrument will be applied after the intervention, before that happens, a numerical validation is applied to obtain a Cronbach's Alpha value of reliability to determine its relevance; and the validity of content through expert judgments, to determine if the wording of the questions is in accordance with the study population.

3.3.2. Application

The surveys will be applied to the study population in the educational establishment through a printed physical questionnaire.

3.3.3. Tabulation of the results

By means of a spreadsheet format, the answers are tabulated, and the associated graphs are generated.

3.3.4. Analysis of the results

Based on the tabulation of the responses and graphs generated, the conclusions and recommendations are proposed.

3.4. Sequence of steps to apply the method

This project is divided into three major stages in which different activities are established to achieve the proposed objectives. Within these three stages, the phases of the agile methodology for the development of SUM systems are adapted. These stages are:

3.4.1. Stage 1. Study and characteristics for the prototype

In this stage, information is collected to select the development tools that will be considered in the prototype development phase. The Educational Institution's lesson plans are reviewed to then select the area and, specifically, the topic on which the creation of the educational content will be focused. The functional and non-functional requirements that the prototype will have, and the description of the use cases are defined.

3.4.2. Stage 2. Prototype development

In this stage, the prototype is developed considering the following activities.

- Creation of the project, specification of configurations and import of libraries.
- Elaboration of image markers.
- Elaboration of 3D models.
- Create the project and adjust the settings.
- Development of the different prototype scenarios
- Performing unit tests.

3.4.3. Step 3. Analysis of the evaluation of the prototype

Once the prototype has been developed, it is installed in the devices. The class is developed in the sessions that correspond to the topic by the teacher, using the devices with the application installed as a resource. Finally, a questionnaire is applied to students to evaluate their experience with the tool in class in terms of its usability and functionality.

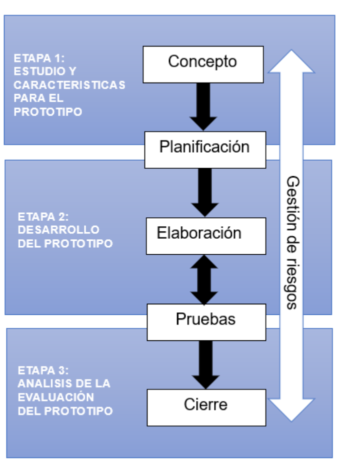

Fig. 3. *Proposed methodology with adapted SUM*

The activities in each phase have been adapted and modified due to the staffing, time and scope constraints in this project.

4. RESULTS

The results obtained are distributed according to the phases of the SUM methodology.

4.1 Concept phase

The concept phase defines the type of application that will be carried out, determining in broad strokes the characteristics that it will have as a name, objective and context, gameplay, setting, the definition of functional and non-functional requirements, its functional architecture (scenarios) and the choice of development tools.

4.1.1. Objective and context

The prototype is called GEVOCUAR, which is an integration or acronym of the words: geometry, volume and body in Augmented Reality. GEVOCUAR is an application that integrates Augmented Reality into educational content to use as a resource in a geometry class in basic secondary education. The context of the project focuses on a rural educational institution and the target audience is eighth grade high school students.

4.1.2. Scenarios (gameplay, setting)

The prototype consists of three scenarios: augmented reality scenario, volume calculator and quiz game. In the first scenario is where the geometric solids are deployed from an image marker and allows students to see them in 3D through Augmented Reality. The second scenario is where the data of the variables referring to the volume formula of each geometric body such as the value of the base, height, radius, among others, are entered and then calculates and shows the result. The third scenario is where a series of questions are presented with four answer options that the student must answer and confirm. At the end of the game, a score is shown depending on the number of correct guesses.

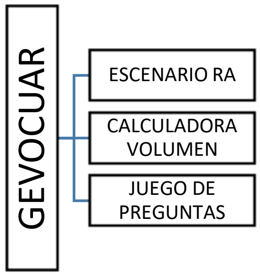

Fig. 4. *Functional architecture of the prototype*

4.1.3. Choice of tools and architecture

The prototype is developed with the Unity 2020.3 engine. Unity is chosen for its wide use in gaming, AR applications, and ease of use. "Unity offers powerful tools to create rich, highly engaging augmented reality experiences that intelligently interact with the real world" [8]. For this project, the Unity Personal plan is used, which is for individual users, hobbyists and small companies whose income or funds raised in the previous 12 months are less than $100.000. The language used in Unity is C#, which is a modern, object-based, type-safe programming language that allows developers to create many types of secure and robust applications that run on .NET [8] [9].

To incorporate Augmented Reality into Unity, Vuforia 10.13 is used, which is selected for its ease of incorporation with Unity and its popularity. "Vuforia Engine is the most widely used platform for the development of augmented reality, compatible with most phones, tablets and glasses. Developers can easily add advanced computer vision features to Android, iOS, and UWP apps to create augmented reality experiences that realistically interact with objects and the environment." [10][14].

Figure 5 presents the technological architecture of the application.

Fig. 5. *Technological architecture of the prototype*

4.1.4. Functional and non-functional requirements

Considering the scenarios that the tool will have, the functional and non-functional requirements were defined. Among the functional ones are:

- Calculate volume: Given the input data such as radius, base, height among others, a result must be given according to the formula.
- Change geometric body: In the volume calculator you must change the body to which you want to calculate the volume by means of two buttons back and forward.
- Project 3D image: The geometric body must be projected in AR once the image marker has been identified.
- Display questions: By pressing the question game button, the first question must be presented.
- Display confirmation message: When a response is chosen, the application must display a message to confirm the response or cancel it.
- Confirm or cancel answer: If the answer is confirmed, the program checks if the answer is correct or incorrect increasing the score or not. If the answer is canceled, the program returns to the question with the options intact.
- Show Next Question: Shows another question. It is only enabled after the previous question has been answered and verified.
- Close the game: Close the quiz game.
- Close app: Closes the app.

Non-functional requirements include:

- Each 3D geometric body should have a different color.
- The typography of the application must be in accordance with the type of users it is aimed at in terms of colors and size.
- The system should have accessible buttons that clearly express the options available.
- The application must adapt to the characteristics of the device, being responsive when changing the orientation and size.
- The system will emit a characteristic audio when a new question is presented, also when the answer is correct and another when it is incorrect.
- The prototype must read the markers perfectly at a safe distance.
- The camera will automatically scan the image marker without the need for any button.

- The result of the volume of the solid is thrown when the input data is entered without pressing any buttons.
- The app works under the Android 8.0 operating system and up.
- The device must have a built-in camera of at least 5 megapixels.
- You don't need to have internet connectivity to use the app.
- The AR scenario must recognize ten markers and display ten different bodies for each.
- The calculator scenario will allow the volume calculation of the ten main geometric bodies with a maximum of three digits for their input data.
- The quiz game does not evaluate the answer to questions without having been confirmed.
- The answer confirmation message in the quiz game should disable the answer options until an option is chosen.

4.2. Planning phase

In the planning phase, a flexible schedule is proposed for the presentation, the definition of the work team or roles, the installation of the development tools and the definition of the use cases.

4.2.1. Interested parties

Among the interested parties of the project are the students who use the application according to the instructions of the teacher and evaluate the application by answering the questionnaire instrument; the teacher, who carries out the class and delivers the devices with the application, giving the respective instructions for use; the rector, who gives his approval to carry out the research in the institution; the parents, who give the go-ahead for their children or attendees to participate in the research and the researcher who installs the application on the devices, delivers them along with the image markers to the teacher and applies the survey to the students.

4.2.2. Work team

According to the roles of the SUM methodology, the work team is composed of: Development team (programmer, graphic artist, sound artist and game designer), internal producer, client, and beta verifier (testing).

4.2.3. Description of use cases

The use cases correspond to the functional requirements identified in the concept stage. The use cases describe the actors, the objective, the basic flow, and the alternative flow.

Table 1: *Description of the use case Designing Solids*

Use Case No. 01	Projecting the 3D Solids
Actors	Student
Objective	Identify the image marker and display the solid in 3D
Basic flow	1. The student runs the app 2. The system activates the camera 3. The student focuses on the marker image 4. The system reads the image and displays the 3D solid on the screen
Alternative flow	1. The system fails to identify the marker 2. The system tries to read the marker again

4.3. Risk Management Phase

This phase is transversal to the entire process development process (all phases). The main risks that could arise are recorded, defining an estimate of their probability and impact, and how they could be mitigated.

A register of risks that were taken throughout the project was carried out where the risk was described and a score from 1 to 9 was assigned in terms of its probability and impact, with 1 being less likely and harmful and 9 being more likely and harmful. The way to mitigate or avoid each risk was also determined.

Table II presents the description of the main risks. The letter P (Probability), I (Impact), and G (Severity).

Table 2: *Risk register.*

DESCRIPTION	P	I	G	ANSWER/ MITIGATION
There is a risk that the project phases will be extended too long, and the project will not be completed within the stipulated deadline due to poor execution of the schedule of activities	5	7	35	Make use of schedule compression techniques. Dedicate more hours per day to the development of the project.
There is a risk that some of the phases of the project will consume more time than expected and cause cost overruns	5	7	35	Dedicate more hours a day to the development of the project after the novelty.

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due to one of the team members getting sick.				
There is a risk that processes can be wrong, and many errors can be generated due to the team's inexperience in development tools.	5	7	35	Write down each deviation from the process as soon as possible and try to correct it. Ask for advice from tutors and experts.

4.4. Preparation phase

In the elaboration, which is an important phase because the success of the prototype primarily depends, the progress is controlled based on the schedule and the objectives set, the scenarios are developed incrementally and errors and problems that arise are corrected.

4.4.1. Elaboration of 3D bodies

We proceed with the creation of the three-dimensional models in Blender that will be displayed when the camera recognizes the marker, as well as figure 6.

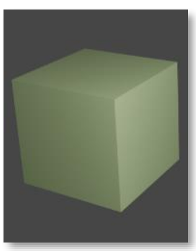

Fig. 6. *Appearance of a 3D solid that is projected when focusing on a marker*

4.4.2. Marker creation

For bookmarks, the database is created in Vuforia Developer's Target Manager and the images are uploaded. Each image represents the net or mold of the geometric body that unfolds with AR (figure 7). These images receive a score by the platform depending on their characteristics such as contrast and sharpness that indicate how optimal the recognition by the device's camera would be.

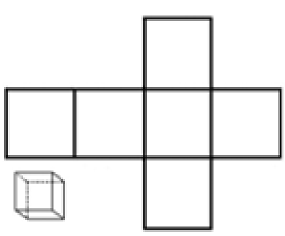

Fig. 7. *Marker image used in the AR scenario*

4.4.3. Development of the menu and scenarios

For the interface, the main menu consists of three fundamental buttons: Calculate, Quiz Game and Exit while it presents the active camera, ready to focus on an image marker to project a geometric body.

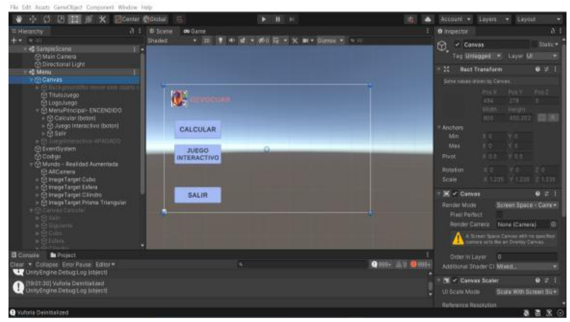

Fig. 8. *Application menu on the Unity platform.*

In the volume calculator scenario as presented in figure 9, the description of the formula with which it is calculated appears and where the values can be entered for the result to be generated.

Fig. 9. *Scenario view volume calculator*

In the game of questions such as figure 10, the first of ten questions is presented, with a marker that shows the number of points depending on the number of correct answers. For each question there are four answer options, among which one is the correct one. The choice of the answer must be confirmed. The app verifies it and enables a button to move on to the next question.

Fig. 10. *Quiz Game Scenario View*

4.5. Testing Phase

In the testing phase (in SUM, beta phase) the general operation of the prototype is evaluated, existing errors and their correction are verified, and in addition, it is verified that the gameplay and events of the prototype work correctly. These tests are done every time an iteration is finished in the development phase.

At the end of the development phase, the APK or executable for Android was generated to evaluate it on mobile devices and is sent to the beta verifier who makes some recommendations that are then adjusted in the prototype.

Table 3: *Change Control Log*

DATE	P	I	DESCRIPTION	EXCHANGE RATE
	Beta Checker	Volume Calculator	Incorporate an image of the geometric body to each screen on the stage.	Improvement
	Beta Checker	Quiz Game	The sounds that are played should not be too long	Improvement
	Beta Checker	General	The items should be more colorful, according to the type of end user.	Visualization

4.6. Closing Phase

The closing phase is the last step of the SUM methodology. This phase is reached when the prototype is installed and applied to the devices with the end users. During this phase, problems, successes, solutions, and achievement of objectives are evaluated, and feedback is given through the analysis of graphs to finally establish conclusions.

4.6.1. Application of the prototype in the classroom

The prototype is installed on the devices by means of a USB cable. The devices are distributed to the students at the times that the teacher requires them according to the moments and activities of the lesson plan [13].

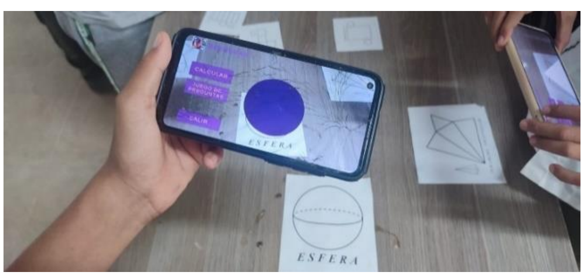

Fig. 11. *Use of the AR scenario by students*

After the class sessions were completed, a validation was made with the students through the application of the survey. Some of the questions involved how they thought of the design, difficulty, improvements to the prototype, and whether they would recommend it for other areas of knowledge, among others [12].

4.6.2. Reliability

Reliability is framed by the instrument's measurements being accurate, stable, and free of any type of error, in terms of the stability of the data. In line with these elements. Reliability is "the quality of an instrument being applied by different researchers in a succession of times to a group of people, obtaining the same results with a degree of accuracy, consistency and precision [11].

Considering the above, the reliability process of the instrument is carried out following the Cronbach's Alpha method, which is a reliability index that explains that "It is the degree to which an instrument produces consistent and coherent results. Consequently, to achieve the result of the coefficient, the answers extracted from the instrument intended to measure the reliability between the research variables are used [11].

Resumen de procesamiento de casos

		N	%
Casos	Válido	25	100,0
	Excluido[a]	0	,0
	Total	25	100,0

a. La eliminación por lista se basa en todas las variables del procedimiento.

Estadísticas de fiabilidad

Alfa de Cronbach	N de elementos
,770	15

Estadísticas de elemento

	Media	Desviación estándar	N
P1	1,00	,000	25
P2	1,00	,000	25
P3	1,96	,200	25
P4	1,00	,000	25
P5	1,08	,277	25
P6	1,56	,507	25
P7	1,00	,000	25
P8	1,00	,000	25
P9	1,72	,458	25
P10	1,04	,200	25
P11	1,00	,000	25
P12	1,08	,277	25
P13	1,92	,277	25
P14	1,04	,200	25
P15	1,08	,277	25

From the above statistical data, it can be analyzed that the reliability of this test is high since its result of Cronbach's alpha is 0.77, determining that it is a reliable position according to the descriptive interpretation of the range of values of the coefficient.

4.6.3. Analysis

The results of the survey are presented represented by means of pie charts and their respective interpretation.

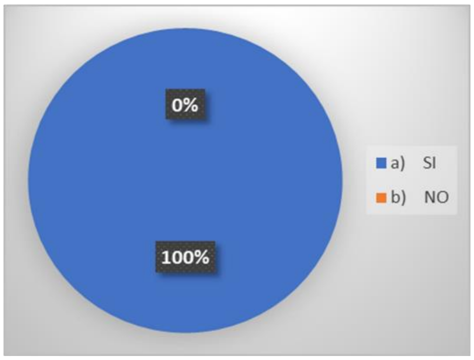

Fig. 12. *Graph with the percentage of students who indicate that the application was comfortable using their fingers.*

This question sought to know about the operability of the application in terms of comfort when using the fingers in people with that age range. All the students answered positively.

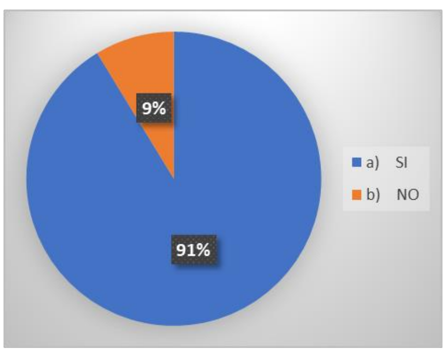

Fig. 13. *Graph showing the percentage of students who consider that the support of these computer programs is necessary for subjects other than Geometry.*

Ninety-one percent of students consider that these applications would be important as support in subjects other than geometry and that it should be more taken into account to use this technology as a support for classes in the academic process of the institution and in this way ICT tools would be integrated into the classrooms.

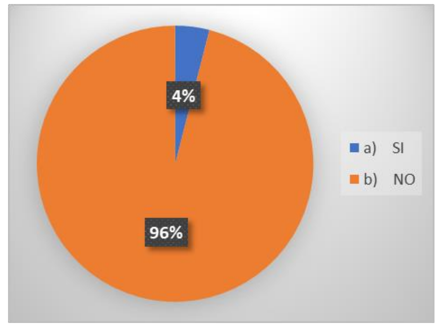

Fig. 14. *Graph percentage of students indicating that there were errors or crashes when using the application.*

Within usability, the criterion of fault tolerance is important to prevent users from making mistakes. In this item, 96% of the students answered that there were no errors or crashes when using the application.

5. CONCLUSIONS

The project resulted in a prototype aimed at the context of a rural and official Colombian school that contributes to the structure of the didactic sequence in a classroom since its modules or scenarios contribute both in the initiation, development and in the closing for a quality class.

This study demonstrates the importance of implementing applications based on Augmented Reality such as GEVOCUAR in the classroom since they can show other didactic nuances to students when working on 3D elements that books could not.

The project contributes to the structure of the didactic sequence in a classroom since its modules or scenarios have to do with both the initiation, development, and closure of a quality class, thus contributing to achieving the goals of SDG 4.

The phases of the chosen methodology were suitable for the development of similar applications and although SUM is a methodology aimed at the creation of video games, it is adaptable to other projects since it allows high flexibility and provides small development teams.

The selected development tools such as Unity and Blender were in line with what was planned to be built. It was wise to make use of Unity by incorporating Vuforia for Augmented Reality since they adapted to the studio's intention to work on the school theme of volume of geometric bodies with the scenarios of a game of questions on the subject and the projection of the colorful geometric solids in 3D.

In the execution of the class sessions with the students, a favorable performance of the prototype and interest on their part in its use were observed, likewise, acceptance results are evidenced in terms of appearance and ease of use.

These applications can be integrated into the classroom for areas other than geometry as a support in the curricula and classes of rural basic secondary educational institutions, in this way, ICT would be integrated to reduce the effects of the lack of integration of technological tools and meet academic objectives.

6. RECOMMENDATIONS AND FUTURE WORK

As a continuation of this research project, researchers and teachers of the institution are urged to expand the applicability of the Augmented Reality software prototype to other areas or subjects of study such as biology, English, social sciences, among others, with special emphasis on the integration of ICT in the classroom.

The geometric bodies in the prototype appear in a static way, it could be interesting that they rotated with the finger to perceive all their parts such as their faces, vertices and edges without the need to move the marker, as well as adding more geometric bodies in addition to the basic ones, such as platonic solids, truncated and oblique geometric bodies and polyhedral with bases on more sides.

Present the questions in the interactive game randomly, as well as the answer options, in such a way that, if the student makes other attempts in the game, the same questions are not presented and in the same order, as well as incorporate some aids or clues.

Strengthen the teaching and learning process of teachers, through training sessions in the use of Augmented Reality tools when they are incorporated into the curricula and the classroom.

Mobile usability is about understanding how people use mobile devices in terms of the way they hold the devices and use their fingers, therefore, it must be taken into account in terms of ergonomics the difference between an application developed for mobile phones (cell phones and tablets) and an application that is deployed on a computer with a mouse or touchpad available.

For future work, it is recommended that researchers interested in incorporating Augmented Reality tools in classroom training plans validate with the teacher the learning axes with the greatest difficulty for the student and verify the technological resources available to educational institutions for research.

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