Towards a Virtual Reality Ecosystem Model to Support Children in Learning Basic Mathematics.

Miguel Angel Ortiz-Esparza[1], Humberto Muñoz-Bautista[2], Luis Angel Arroyo-Morales[1], Claudia Acra-Despradel[3] and Klinge Villalba-Condori[4]

[1] *Center for Research in Mathematics, Quantum Knowledge City, Zacatecas, Mexico*
[2] *Universidad Autónoma de Aguascalientes, Av. Universidad # 940, Ciudad Universitaria, C.P. 20100, Ags, Ags. México*
[3] *Universidad Nacional Pedro Henríquez Ureña, Santo Domingo, Dominican Republic.*
[4] *Universidad Católica de Santa María, Urbanización San José s/n, Arequipa, 04013, Perú*

Abstract

Nowadays, the teaching of mathematics has been modified as electronic instruments advance. Throughout history, teaching has evolved in an impressive way. Today, education is not immune to all these changes, and therefore, it relies on current technology. One of the most important branches of this evolution in mathematics education is virtual reality. In Mexico, there are several lines of research to develop mathematical skills. This is why this work conducts an investigation into the implementation of virtual reality applied to mathematics education with a pedagogical focus and supported by a multidisciplinary group. This is achieved through an ecosystem model that helps create, implement, and provide feedback on current technology. This work proposes a case study, its implementation, and the acquisition of implementation results, which are subsequently analyzed.

Keywords
Realidad virtual, ecosistema digital, matemáticas, educación básica.

1. Introduction

Elementary education is fundamental to establish the foundations of knowledge for future professionals. It is especially crucial to develop a solid understanding of basic sciences and mathematics. However, the COVID-19 pandemic has brought about a transformation in the way education is delivered, incorporating the use of technological tools to offer virtual education, which is becoming a trend for the future of education.

This approach has had a significant impact on math learning outcomes, both for students and teachers at all educational levels [1]. In response to the effects of the pandemic, education has had to evolve, and emerging technologies such as virtual reality (VR) and augmented reality (AR) have emerged as alternatives to provide distance education [2]. These technologies have the potential to be used as asynchronous and remote tools that allow students at any level to interact with educational content at a time and place that suits their needs and learning conditions [3].

According to data presented by the OECD (Organization for Economic Cooperation and Development) in 2018, through the Programme for International Student Assessment (PISA), Mexico significantly lags behind the average in reading, mathematics, and science skills.

Regarding mathematical skills, it is observed that 56% of students show an insufficient level of competence, while only 0.5% manage to reach a level of excellence. These data contrast significantly with the previously presented report, where 24% and 11% were recorded, respectively [4]. Likewise, according to the results obtained in the PLANEA test (National Plan for

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miguel.ortiz@cimat.mx (M. Ortiz-Esparza); hmuntista@gmail.com (H. Muñoz-Bautista); luis.arroyo@cimat.mx (L. Arroyo-Morales); c.acra@unphu.edu.do (C. Acra-Despradel); kvillalba@ucsm.edu.pe (K. Villalba-Condori)
0000-0001-8762-5780 (M. Ortiz-Esparza); 0000-0003-1720-0554 (H. Muñoz-Bautista); 0000-0002-6834-4796 (L. Arroyo-Morales); 0000-0002-6429-5675 (C. Acra-Despradel); 0000-0002-8621-7942 (K. Villalba-Condori)

the Evaluation of Learning) applied in 2018 to sixth grade primary school students, 59% of students have an insufficient level in mathematics, in contrast to the 15% that reach a sufficient level and 8% that achieve an excellent level [5].

Considering the findings mentioned above, the objective of this work is to propose and evaluate an ecosystem model of virtual reality environments that contributes to improving mathematical skills in basic education. Virtual reality (VR) environments will be used with a playful design that encourages learning, taking advantage of the intrinsic capacity of virtual reality to motivate and capture attention in pedagogical aspects [6].

2. Related Works

One of the most relevant theories in the acquisition of initial knowledge in the history of humanity is, without a doubt, Piaget's theory. These theories generate basic and fundamental concepts in the educational field, allowing us to understand how children acquire knowledge and cognitively evolve through different stages or stages. In this work, we consider it vitally important to identify the characteristics of each cognitive stage to adapt teaching methodologies and teaching resources to the needs of each student [17].

In that same sense, the use of Virtual Reality-Learning (VR-Learning) can be a valuable tool to improve the understanding and learning of mathematical concepts in children. VR creates an immersive and interactive environment that facilitates learning and understanding mathematical concepts in a playful and entertaining environment.

A practical example of this is the course “Practical Virtual Reality with a Focus on the Magic Mobius Strip” [18], which shows how VR can be used in mathematics teaching. This course uses three-dimensional models to represent a paper ring with the color red on the front and the color green on the back.

Other examples of the use of these technologies include the work "Design of Immersive Virtual Reality for the Teaching of Geometry" [19], which presents a system that uses collaborative augmented reality as a teaching method and uses dynamic 3D geometry to support mathematical and geometric education in secondary school. This system allows students to collaborate and work together in solving mathematical and geometric problems.

A similar example is the application “VRMath: Building 3D Geometry Knowledge in Virtual Reality Worlds” [20], which has developed a prototype VR learning environment called VR Math for learning 3D geometry. The virtual reality interface provides 3D representations of objects that allow students to interact with them and explore complex mathematical and geometric concepts.

In the context of mathematics and physics education, the work "Virtual Reality Simulations in Mathematics and Physics Education" [21] is presented, which shows several VR models for teaching these subjects. These models help students analyze and understand complex mathematical and physical concepts and problems.

The study “Study of Mathematical Geometry Learning Enhanced by Immersive Virtual Reality Technology” [22] describes an investigation into the use of immersive virtual reality technologies in teaching mathematical geometry. An immersive virtual reality learning system is used to teach mathematical geometry concepts. The experimental results show that the use of this system can improve students' motivation and learning performance in this field. This study indicates that the use of emerging technologies and digital teaching aids is becoming a trend in mathematics teaching.

Finally, the work "Geometry Explorer: Learning Enhanced by Immersive Virtual Reality Technology" [23] presents the "Geometry Explorer", a virtual reality system that helps students learn 3D geometry. This system uses a Samsung Gear VR device to allow users to view and manipulate the size of three-dimensional shapes. Additionally, the system includes a game that challenges users to calculate the volume of shapes.

In summary, the use of virtual reality in mathematics education has proven to be an effective tool to improve the understanding and learning of mathematical concepts. Various studies and applications have explored the potential of virtual reality in the educational context, both in the

teaching of geometry and in other areas of mathematics and physics. These emerging technologies are changing the way mathematics is taught and learned, providing interactive, immersive, and motivating experiences for students.

3. Problem detected

First of all, it is essential to define the concept of learning in the context of this research. According to the UNESCO definition, learning refers to the continuous and dynamic process by which an individual acquires skills, knowledge and attitudes through his or her interaction with the environment [7].

On the other hand, it is important to clarify the concept of teaching, which is the process through which learning is facilitated by providing students with the skills and knowledge necessary for their development. The objective of teaching is to create an environment that encourages learning and allows students to achieve the proposed objectives, taking into account their individual and social characteristics [8].

3.1. Mathematic´s importance in Learning

Mathematics, as a formal science based on the principles of logic, studies the properties and relationships of abstract entities, such as numbers, geometric figures, magnitudes and structures. Furthermore, mathematics is a powerful tool for solving problems and making decisions in different areas of knowledge. Therefore, it is essential that students develop logical mathematical thinking and the skills to apply mathematics in real situations [9].

3.2. Attention problems

Attention plays a crucial role in learning school subjects [11]. However, various studies [12], [13] have shown that distraction is a frequent phenomenon that negatively affects the teaching and learning process, decreasing academic performance, motivation and self-esteem of students. Distraction can have an emotional origin or be related to external factors, such as noise, temperature, lighting, personal problems, and lack of interest, among others. Although the attention of primary school students depends in part on their neurological development and individual characteristics, it has been shown that attention can be improved through the use of innovative teaching strategies adapted to the needs of students [14].

3.3. Lack of access to technology

The lack of access to technology in educational institutions limits the possibilities of students and teachers to use technological resources such as computers, tablets, electronic whiteboards, among others. This situation has a negative impact on student learning, especially those who are in vulnerable situations[23][24]. According to the data presented in the Study of the impact of ICT on students [16], the appropriate use of information and communication technologies (ICT) could improve the academic performance of students with low socioeconomic and cultural levels, as well as improve your standards of knowledge acquisition.

This work addresses the problems related to learning and teaching, emphasizing the importance of mathematics and mathematical competencies. In addition, attention problems in the educational context and the heterogeneity of knowledge levels among students are analyzed. Finally, the lack of access to technology and its impact on student learning is examined.

4. Proposed model

In this section, the proposed ecosystem model for learning mathematical skills in virtual environments for basic education students is presented. The main proposition of an ecosystem

consists of four key components: producers, media, consumers and products. Each component plays a fundamental role in the development and implementation of virtual environments aimed at improving students' mathematical skills. Each of the elements of the proposed model are described below according to Figure 1.

Figure 1: Proposed ecosystem model for the implementation of virtual reality environments at basic education levels

4.1.1. Producers

Producers are groups of developers or technologists dedicated to designing and developing quality virtual environments. Its primary goal is to support the learning of mathematical skills by providing students with an interactive and enriching environment. To achieve this, developers must work closely with teachers, who have valuable information about content, educational objectives, student profiles, and their individual needs. The feedback that teachers provide to developers about students' use of virtual environments is particularly important, as it helps them improve and refine the design of these environments.

4.1.2. Means

The media are the platforms, repositories or channels that facilitate teachers' and students' access to these applications. They may include app stores, websites, or other digital media. It is essential that the media provide a safe and efficient experience, allowing the download, installation and use of virtual environments in a simple and accessible way for all users. In this way, teachers and students will be able to take full advantage of the educational advantages that these environments offer.

4.1.3. Consumers

Consumers are students and supporting teachers who use virtual reality environments as an additional tool to strengthen their mathematical skills in a playful and motivating way, taking advantage of the features of virtual reality. Students must use the virtual reality environment in accordance with the instructions and guidance provided by teachers and developers. This helps students achieve their set learning objectives and get the maximum benefit from these applications.

4.1.4. Products

Products play an essential role in this ecosystem. These can be both the generated applications and the data obtained from feedback from the use of the same applications. The data includes the results obtained by students in the activities carried out within virtual environments, as well as the feedback they express about their learning experience. Producers must collect and analyze this data to obtain valuable information that allows them to improve the design and development of virtual environments. Likewise, teachers can use this data to evaluate students' progress and areas of opportunity, adapting their teaching according to the detected needs of each student.

4.2. Design of the Virtual Environment for Learning Mathematical Skills

This section details the definition of a virtual environment, as presented in Figure 2, and the identified characteristics that it must possess to facilitate the learning of mathematical skills.

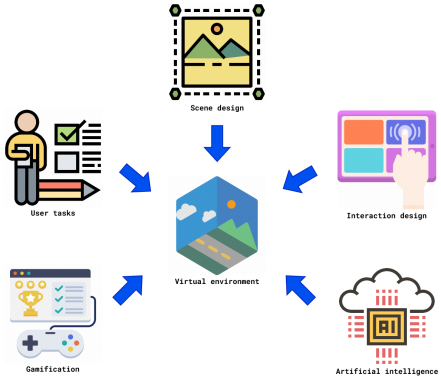


Figure 2: Componentes propuestos para el diseño de un entorno virtual como soporte al aprendizaje de las matemáticas.

4.2.1. Definition of a Virtual Environment

A virtual environment is an application that simulates a three-dimensional scenario where the user can interact with objects and perform tasks related to learning mathematical skills. For a virtual environment to be effective, it must have the following main characteristics: a realistic scenario, the user's interaction with the environment and objects, the application of gamification principles, the definition of a main activity that the user must perform, and the ability to manage the difficulty of the main activity.

4.2.2. Gamification in the Virtual Environment

Gamification is a strategy to improve activities, systems and other aspects, through the creation of experiences similar to those experienced in games, with the purpose of encouraging and involving users. In the virtual environment, gamification is mainly used in the design of scenarios, interactions and scoring systems, with the aim of generating an attractive and recognizable experience for users.

4.2.3. User Tasks

User tasks are the actions that the user performs to complete the main activity in the virtual environment, such as moving, cutting, or selecting objects. These tasks constitute the main element of the virtual environment and have different characteristics, such as the level of difficulty, the expected results, among others.

4.2.4. Stage Design

The scenario design aims to offer a gaming experience that allows the user's tasks to be solved. It must be focused on the users, in this case, primary school students. In the stage design, the 3D models of the objects and their appearance are defined. Not all objects will be interactive; some will remain static. Only the objects necessary to solve the tasks will be dynamic and respond to user interactions.

4.2.5. Interaction design

Interaction design is crucial to define the actions that users will perform when interacting with the objects present in the scenario. The interaction is materialized through interfaces that allow users' actions to be captured and processed. It is important that interactions are intuitive and easy to use for users, especially those who have not had prior experience in virtual reality environments. Therefore, interaction design should focus on providing a friendly and accessible experience for users.

5. Case study

This section presents a case study, in which the ecosystem model previously described in Section 4 is implemented. The objective is to provide a detailed description of the implementation of the ecosystem, focusing on each of its modules and the process of application of virtual reality environments.

5.1. Study design

The case study presented below was carried out during a period of 3 months of visits to the primary schools **"CECID primary and preschool"** located in the central area of the city of Aguascalientes in the capital of the same state and the "**Francisco y Madero Elementary School"** located in the community of "**la pimienta"** in the capital of the state of Zacatecas. The visits to these schools were carried out twice a week in order to observe the behavior of the students. The design of this research is a multiple case study because it´s a research that uses a quantitative methodology that is It focuses on search processes and systematic analysis of the mathematical skills of one or more students. In addition to the above, it is a longitudinal case study because it´s an observational study that collects qualitative and quantitative data from the consumers of the ecosystem (teachers and students). and is responsible for repeatedly improving the monitoring of students with learning problems in basic mathematics over an extended but limited period of time and, being a type of longitudinal case study design, due to its nature, it tends to be an observational design.

5.2. Participants or sample

The selection of the sample for this case study originated based on the knowledge and expertise of the support and regular education teachers found in each of the aforementioned primary schools, the procedure for detecting students with problems. The learning process is based on quantitative variables that measure the acquisition of basic knowledge of each of the students in the different skills. If a student has problems acquiring knowledge, it is quickly detected by their failing grades and their difficulties in expressing mathematical knowledge in question.

During the first visits to the primary schools, the support teachers had identified 5 students with learning problems in the primary school in the state of Aguascalientes and 6 students with learning problems in the primary school in the state of Zacatecas, the profile given by the staff of the primary for each of the detected children is described below in the following table.

Table 1

User profiles corresponding to children with learning problems at the CECID primary school (Aguascalientes).

Student	Degree-Group	Diasgnostic
Student-1	3°A	ADHD
Student-2	3°A	Difficulty in learning
Student-3	4°A	Lack of attention and concentration
Student-4	5°A	Autism
Student-5	6°A	Intellectual disability

Table 2

User profiles corresponding to children with learning problems from the "Francisco y Madero" primary school (Zacatecas)

Student	Degree-Group	Diasgnostic
Student-1	2°A	Difficulty in learning
Student-2	3°A	Difficulty in learning
Student-3	4°A	Lack of concentration
Student-4	4°A	Lack of attention and concentration
Student-5	4°A	ADHD
Student-6	5°A	ADHD

5.3. Instruments and Tools

The evaluation instruments used are those provided by the USAER (Regular Education Support Services Units), these are divided into three cycles; for the first and second grade of basic education, it is considered the first cycle USAER, the third and fourth grade of basic education is considered the second cycle USAER, and the fifth and sixth grade of basic education is considered the third cycle USAER.

Below are the evaluation instruments used to quantitatively measure progress in the three different cycles for children who have learning problems at any of the levels of basic education at the primary level.

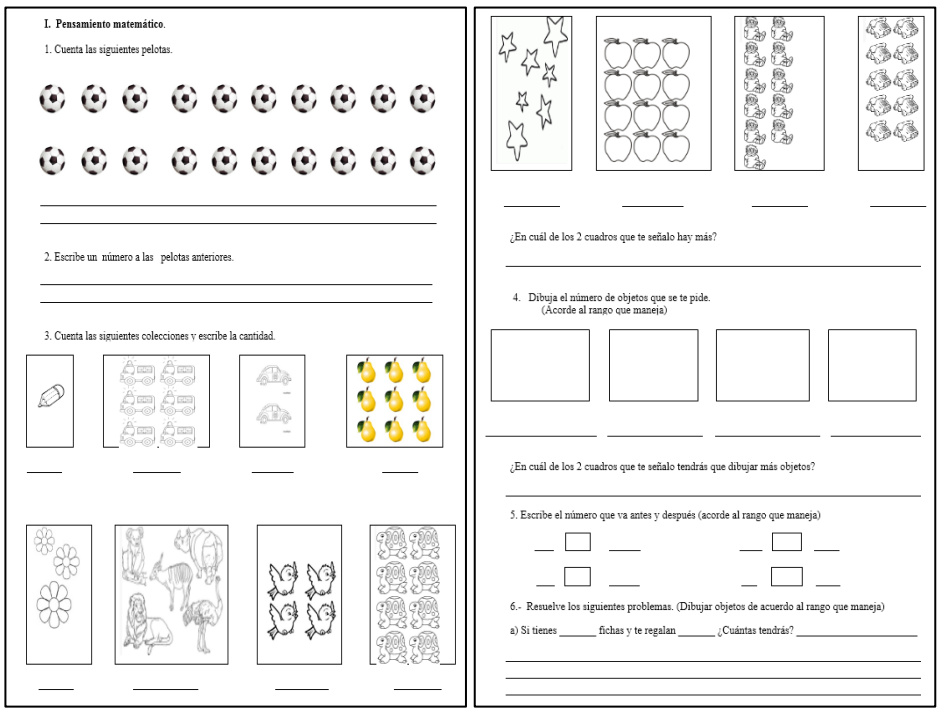
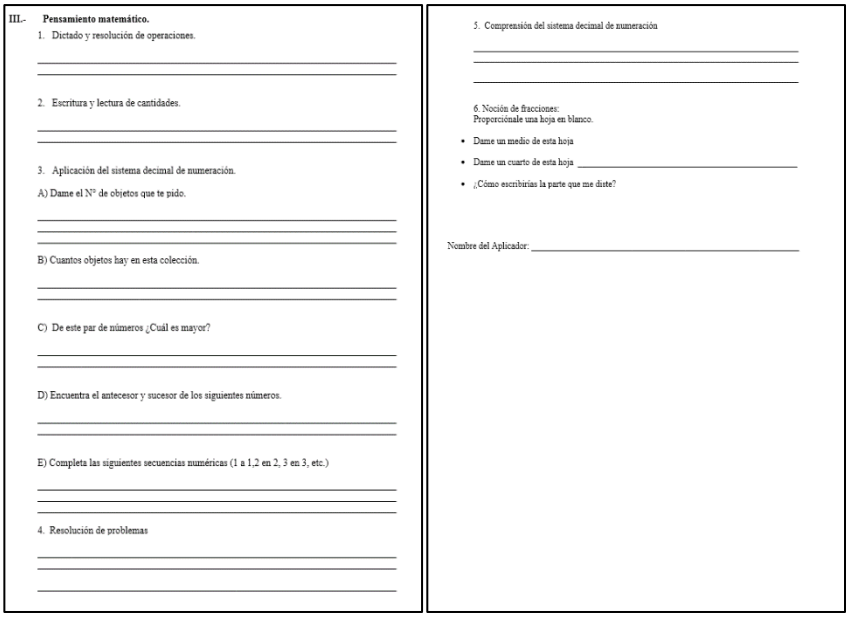


Figure 3: USAER Cycle 1 Assessment Instrument



III.- **Pensamiento matemático.**

1. Dictado y resolución de operaciones.

2. Escritura y lectura de cantidades.

3. Aplicación del sistema decimal de numeración.

A) Dame el Nº de objetos que te pido.

B) Cuantos objetos hay en esta colección.

C) De este par de números ¿Cuál es mayor?

D) Encuentra el antecesor y sucesor de los siguientes números.

E) Completa las siguientes secuencias numéricas (1 a 1,2 en 2, 3 en 3, etc.)

4. Resolución de problemas

5. Comprensión del sistema decimal de numeración

6. Noción de fracciones:
Proporciónale una hoja en blanco.

- Dame un medio de esta hoja
- Dame un cuarto de esta hoja
- ¿Cómo escribirías la parte que me diste?

Nombre del Aplicador:

Figure 4: USAER Cycle 2 Assessment Instrument

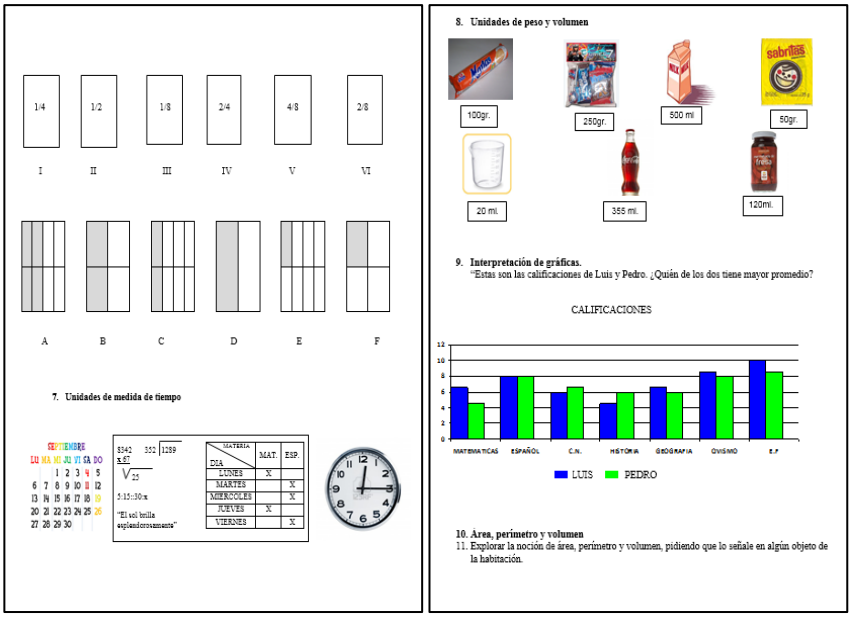
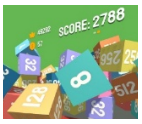


Figure 5: USAER Cycle 3 Assessment Instrument

5.4. Procedures

Once the students were identified, the evaluation instruments were applied and the user profiles were obtained, which are detailed in tables 1 and 2 in the previous sections. Based on the user profile of each student, they began to search for virtual reality applications that would help mitigate the problems presented by each student and with this information the following table of applications that help improve was constructed.

Table 3
Table of virtual reality applications that help mitigate mathematical problems presented by basic education students

Icon	APP Name	Description	Math Skill
	Math VR	Solve basic operations by choosing the correct numbers that appear on the field and get points.	Arithmetic problems
	Medieval Math VR	Solve basic operations by choosing the correct result and you will obtain arrows to defend the castle from the enemy army.	Arithmetic problems
	Cubeling VR	It´s a teaching application to promote spatial imagination in mathematics classes. Allows you to build cubic buildings in a shadow box.	Space-time discrimination
	The VR Sudoku Game	In this VR game, you solve Sudoku in a physical space by placing numbers in slots on the board. The goal is to fill the 9x9 grid with digits so that each column, each row, and each of the nine 3x3 subgrids that compose it contains all the digits from 1 to 9	Graphic information processing
	Math World	This is an educational math game packed with fun mini-games with challenging math problems for the whole family to enjoy. Each minigame has its own mathematical obstacles and your job is to beat the high score.	Recognition of numbers and operators
	2048 blocks VR	Match the blocks and reach 2048 in this simple VR puzzle game. If 2 blocks of the same value touch each other, they will merge and add together. You will also get a coin for each block you match.	Short and long term memory

Once the table of applications and their main functionalities were built in favor of the development of mathematical skills, virtual reality environments began to be implemented in children. For this case study, the analysis of two applications was carried out, which are described below. detail

In this case study, the producers are external agents that develop virtual reality applications in software demonstration mode, which is why we use them to obtain feedback on their implementation.

The means through which the products are stored and transferred is through local storage devices that are carried and transferred in the same primary school. It is intended to improve this aspect so that in future iterations it will be through a repository. of virtual reality applications.

The products that were used in this case study are two virtual reality applications that were implemented over a period of 3 months. In the primary school of the state of Aguascalientes, the **"Medieval Math VR"** application was implemented, which is described in **"Table 3."** the same that helped with the number recognition problems that they presented in the **"CECID"** primary

school, on the other hand in the Zacatecas state primary school **"Francisco y Madero Elementary School"** the **"Virtual Math VR"** application was implemented that helps with the strengthening mathematical skills in the area of arithmetic operations as described in **"Table 3"** the experiment consisted of the frequent use of the application and the application of the instrument in the skill that is being worked on for each of the areas.

5.5. Data analysis

In the first instance, user experience data and usability of virtual reality applications were analyzed, for which the necessary questionnaires were applied and the following data were obtained.

Factors	Scale						
	Nothing	Very Little	Few	Something	Quite	A lot	Very Much
Cognitive involvement	0%	0%	10%	6%	9%	9%	66%
Emotional Implication	0%	0%	3%	4%	4%	4%	85%
Dissociation from the real world	0%	0%	5%	3%	0%	5%	87%
Control	0%	0%	8%	19%	3%	8%	62%
Challenge	52%	5%	22%	2%	2%	2%	15%

The data is based on the collection of data from surveys carried out directly to basic education students in the state of Aguascalientes, these results show the group percentage on the factors to measure the level of immersion of the virtual reality application "Medieval Math VR"

Factors	Scale						
	Nothing	Muy poco	Nothing	Something	Nothing	Mucho	Nothing
Cognitive involvement	0%	0%	10%	6%	9%	9%	%
Emotional Implication	0%	0%	6%	4%	5%	7%	92%
Dissociation from the real world	0%	0%	5%	3%	0%	6%	90%
Control	0%	0%	8%	19%	3%	13%	62%
Challenge	55%	6%	27%	3%	3%	3%	18%

The data is based on the collection of data from surveys carried out directly to basic education students in the state of Zacatecas, these results show the group percentage on the factors to measure the level of immersion of the "Virtual Math VR" application.

5.6. Study Limitations

The limitations that we have for now in this case study are the number of students, a larger number of communities are required where we can test the ecosystem, for now only the evaluation has been carried out with two applications, but the aim is to increase the number of virtual reality applications in order to make a more complete evaluation.

Also, as future work, it is intended that these applications be found in a repository that is available at all times and that the applications can be downloaded at any time from almost anywhere.

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