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Serious Video Game as Mediator of Geometric Representations - Algebraicas of Quadraphical Surfaces

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Abstract We present the results of a research whose objective was to promote visualization skills in engineering students of the Technological Institute of Cd. Guzmán, in the appropriation of the concept of quadratic surfaces. For which, it is proposed the implementation of a serious videogame called "Quadratic Identity" where the student related two records of semiotic representation of said concept, designed in an immersive virtual reality environment and based on the user-centered methodology for its design, considering both the concepts of gamification, those proposed by serious video games. The user must have access, before playing, the theoretical part of the mathematical concepts treated and then play to evaluate this theory. A qualitative study was developed to show if through the videogame, learning is promoted in the student regarding the transit between the semiotic registries considered, finding positive results and growth opportunities of the proposal.

Keywords: *virtual reality, semiotic records, quadratic surfaces, immersive environments*

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1. Introduction

The vector calculus is one of the disciplines offered in the first semesters of engineering careers at the National Technological Institute of Mexico [1]. In this subject, we study various mathematical objects that involve three-dimensional space, among which stand out cylinders and quadratic surfaces. When these objects are addressed in the classroom, students must develop skills that allow them to identify them, first, from their mathematical model, as well as characterize them geometrically according to said model.

It has been observed that, in this process of characterization, students present difficulties mainly in the visualization of the model, as well as describing and obtaining information from the different geometric perspectives of the treated solids. This process of visualization is important, since it leads to another type of mathematical approach, to mention some: the calculation of areas between regions and volumes of solids with multiple integrals, approaches involving gradients and directional derivative, centers of mass, areas of surfaces, among other [2]. If the student does not have visual skills to interpret the geometric behavior of these three-dimensional figures, it will not be possible to specify the construction of other mathematical concepts that allow him to mathematize situations of his environment (as mathematization is understood as the ability of an individual to move the information of a context to the mathematical world, give it a treatment and return it to its original context, [3]).

A playful scenario based on immersive virtual reality was developed, whose main objective was to promote skills in the geometric visualization of the mathematical objects cited. The proposal was developed from two viewpoints; the first one consisted of a virtual simulator where the theoretical foundations of the concepts that introduce the study of quadratic surfaces. In the second one, a videogame was developed in 3D, whose main objective was to evaluate the skills in the visualization of mathematical objects in R^3, to analyze them in their real dimension, characterize them according to their traces until the identification of the links between the records of representation, geometric and algebraic.

The study was based on two aspects; On the one hand, theoretical support was needed to understand how mathematical knowledge is constructed. In accordance with the skills that are intended to be promoted, the theory of Semiotic Representations will be incorporated, since the virtual scenario establishes a symbiotic relationship between geometric representation registers and algebraic registers. [4].

On the other hand, it was necessary to create a virtual scenario that is pleasant (that the user understands its use in an easier and more natural way) with the users, since that promotes a greater understanding of the mathematical concepts and the development of skills of visualization in three-dimensional Euclidean space. In addition, following the idea of a friendly scenario, the immersive virtual reality was used in order that the user has a greater perception of mathematical objects within that virtual world.

2. Context

The vector calculus is a discipline that is offered in the first semesters of the engineering careers of the National Technological Institute of Mexico [5], in which diverse mathematical objects are studied, among which the vectors stand out, coordinates in different systems of representation, functions of several variables, partial derivatives, multiple integrals, among others.

It is the subject where the three-dimensional Euclidean space is addressed for the first time in a formal manner, which consists of a structure constituted by three mutually orthogonal axes, where the first challenge faced by the students is to locate rectangular coordinates, which require strokes that should be represented on a flat surface, such as a sheet of paper or blackboard. In Figure 1, we have the point P (1, 2, 1) represented in R^3.

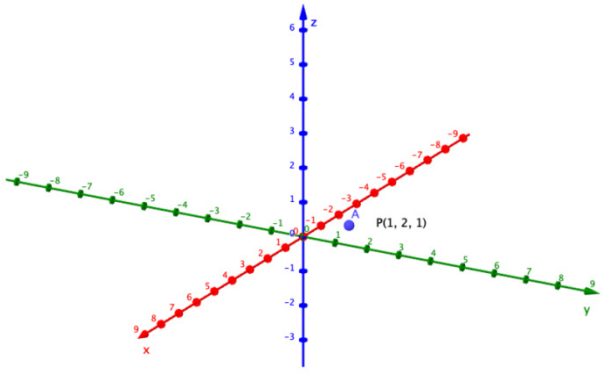

Figure 1. Three-dimensional Euclidean space

When the students take the course, it is expected that they will develop the necessary knowledge and skills so that they can trace geometric shapes from mathematical models and vice versa, since this is necessary to address more complex concepts such as calculating areas between regions, volumes of solids with multiple integrals, approaches that involve gradients and directional derivation and centers of mass, to mention a few [2]. Within the classrooms, it has been observed that there is difficulty in the students to geometrically visualize the models, describe and obtain information of the different perspectives and intersections of the solids treated.

A very common mathematical situation that occurs in the classroom is to find volumes of specific surfaces, which do not obey a common mathematical model such as those proposed in geometry books, for example, as shown in Figure 2. The problem is to calculate the volume of the surface that is generated at the intersection of two circular cylinders of radius **r**.

The main problem faced by the students is to interpret the form that is generated in said intersection and they lack visualization skills of the third dimension, additionally with the fact that they must make tracings on a paper, which represents a flat surface and if the student or the teacher, lack drawing skills, the situation will become even more complicated.

a) Intersection of two pipes b) Volume that forms at the intersection

Figure 2. The intersection of two pipes

In Figure 2, the intersection of two pipes is observed, a real problem that occurs in the classroom, the objective is to calculate the volume of the surface that is generated in that intersection. This is complicated for students who lack visualization skills and therefore, are not able to extract essential data to generate the mathematical model of the surface, so it becomes imperative to propose didactic proposals that contribute to the development of skills for the visualization of graphs in three-dimensional space and its relationship with its mathematical model.

3. Background

Currently, virtual reality is increasingly incorporated into educational scenarios, but there is still scarce scientific production that exists because it is a new field. However, we have found some approaches to this technology oriented to teaching, for example, a work that addresses the performance of graduates of the electrical engineering career in a competitive and globalized world and how it is diminished compared to other countries, since there are conditions that affect poor student preparation. Then, the creation of a virtual world is promoted in which systems that are not counted in laboratories can be analyzed.

On the other hand, Ponce et al [6] propose an application through augmented reality that shows three-dimensional objects called augmented geometrical bodies to observe the interest generated by using this type of technology in teaching in the basic study. However, within this investigation the manipulation of objects and concepts of the Euclidean space was not addressed only the information of the three-dimensional objects was present. In the present work it is tried to modify and to manipulate the physical form of the three-dimensional objects and to observe the repercussions that this entails in the corresponding mathematical model.

In another proposal [7], an immersive virtual reality application is created that uses the technology provided by Leap Motion to manipulate three-dimensional objects and in this way test the impact that students of the fourth grade of elementary school have when defining concepts. of faces, edges and vertices. However, this project did not seek to consider the understanding of the Euclidean space as it is intended in this research.

The immersive virtual reality application in mathematics is not common, there are still few works that exist about it. There is an investigation [8], in which a study plan is proposed which shows the learning that students show in an immersive virtual reality in comparison with the learning in a common classroom. For this, a virtual world that can be used freely known as SeconLife is used to make sections of classes within it. Improved student learning was observed compared to students who attended face-to-face classes (without access to SeconLife). The aim of this research is to document the scope that can be achieved for understanding the concepts of two-dimensional and three-dimensional Euclidean spaces through interaction with a virtual world in which students perform various activities within that virtual world.

On the other hand, we studied the case of side effects that can occur with the use of virtual reality, in which several conclusions were reached [9]. After conducting several tests with diverse groups, it was concluded that the excessive use of this technology creates strong side effects such as dizziness, headache, loss of balance and tired eyesight, but it was concluded that with a routine not so strenuous of continuous days using technology you get a tolerance to those side effects and makes it easier to use it.

4. Theoretical Fundament

The research was based on two approaches, first it was necessary to understand how the mathematical thought of an individual takes place, for what epistemologically is based on the theory of semiotic representations. On the other hand, it was necessary to theorize the learning scenario, based on the theory of serious video games mediated in immersive environments.

4.1. Registries of Semiotic Representation

Semiotics refers to the science that studies the signs or the different systems of signs in which we can describe a concept, in this case the algebraic representation that corresponds to the mathematical model and geometric representation corresponding to the three-dimensional shape that corresponds to a quadratic surface.

Duval, calls semiosis to the activity linked to the production of representations, which depends on the signs that are part of the system used to generate them, and noesis to the activity linked to the conceptual apprehension of the objects represented, including the different activities and cognitive processes developed by the subject [10].

According to Duval, semiotic systems must allow three cognitive activities which are:

- To be able to find the characteristics of an object or concept and in this way to represent it within a concrete semiotic system.
- Be able to use the representation of the concept or object and be able to apply the rules, functions and laws of the system of semiotic representation, leading to a more complete and profound learning that only the representation within the system.
- Be able to use the representation of the concept within the system and be able to move it from one representation to another, in another different semiotic system.

When Duval mentions the registers of semiotic representation, it refers to the existence of different semiotic systems, within which the same concept can be represented, but characterized differently in each system and can be treated and studied from different approaches of each system semiotic [4].

So that mathematical objects are not confused with their representations and are able to, first, recognize the same object of knowledge through representations whose contents have no relation to each other, and, second, recognize and distinguish two objects through two representations whose contents seem similar because they depend on the same system of representation, it is essential to be able to mobilize different registers of semiotic representation (natural language, functional language, algebraic language, graphic, figures, etc.) and develop coordination among them. [11].

Duval [12] says: "the comprehensive understanding of a conceptual content is based on the coordination of at least two records of representation, and this coordination is revealed through the rapid use and spontaneity of cognitive conversion" (p. 46).

Considering this idea, it was necessary to implement at least two different representations of the same concept within the serious video game and generate the relationship between both in real time, so that the user can understand the relationship between the mathematical model and its graph. For this, it was necessary that within the serious videogame both the mathematical model and the graph can be modified by the user and in this way, the changes are perceived that impact either by modifying the mathematical model and observing the changes in his graph or by modifying its graph and observing the changes in the mathematical model. Once the user interacts with the theory of the concepts, he continues with his self-evaluation through the video game, where the user's achievements are reported through a scoring system that shows his success.

In the proposal that was implemented, a system was made that reflects in real time the relationship that exists between the mathematical model (equation that defines the quadratic surface) and its graphic model (three-dimensional model that represents the quadratic surface), this was implemented making modifications to the parameters of the mathematical model and that these are reflected in the corresponding graph in the three-dimensional Euclidean space.

For the user to identify the relationship that exists between these two semiotic registers, it was necessary to implement the representation of the change of register in vice versa, which means that when the three-dimensional graph is modified, its changes are reflected in the mathematical model, in this way it is expected that the user can interpret this relationship in a more efficient way, unlike how it is explained in a classroom with a teacher in a conventional manner, which means that the teacher explains this relationship with an abstract object and tries to show it in the painted the mathematical model and its graph in third dimension by means of traces without the possibility of observing from different angles the graph or its variations when modifying the mathematical model. In

addition, there is no way that the teacher can represent with a fidelity that exceeds the acceptable quadratic surface graphics, which can be achieved with the implementation of virtual reality.

4.2. Virtual Reality

Currently there is no agreement regarding the definition of virtual reality but after analyzing the different definitions proposed it was defined that virtual reality refers to immersed sensory simulation of the world or fantastic worlds, where you can see, hear, use and modify objects [13]. The concept of immersive Virtual Reality is a term that is used to allude to make the user believe that he is inside the world generated by the computer and not only as a spectator. It has been shown in numerous studies that virtual reality technology is a powerful tool for teaching, mainly because of its ability to promote immersive, multisensory and credible environments [13].

However, most systems or applications that are currently under development within universities do not have the advice of an educator or instructor in the use of educational technology, so it is necessary to know what is virtual reality? and When and where can it be applied? [13].

In general, a virtual reality system is constituted by several subsystems that together with software and hardware, allow the user to interact with the virtual space and generate in the user the "illusion" of immersion, depending on different configurations that are can be used to generate the system can be classified into different levels of immersion ranging from the least immersive are called "virtual reality desktop" systems that basically involves systems that have a communication interface with the user a monitor, a mouse and a keyboard, even the most advanced that are called "Immersive Virtual Reality" systems, which are those that involve more advanced interfaces such as helmets, gloves, motion detection sensors, positioning sensors, it should be noted that the immersion is given to the extent that it is difficult for the user to perceive that he is not inside the world or virtual [13].

The concept of immersion was reflected from the creation of the first virtual reality systems which were simulators of flights created to train the pilots with flight training, for which the simulators had to fulfill four important characteristics, the first was the one of generating a wide visual field that allowed them to use the peripheral vision, second to detect the position and attitude of the user's body, the third was that the system allowed to monitor the natural behavior of the participant and fourth to avoid a significant delay at the speed at which the virtual world is updated in response to the user's actions, these four conditions are necessary to achieve the "Immersive Virtual Reality" achieving in the user a sensation of being inside the virtual world called as "cognitive presence". The disappearance of the human-computer interface is necessary to achieve complete immersion within the virtual world. [13] With the use of immersion two situations are generated that are useful to education, the first is that the user loses sight of the boundary between him and the information of the computer and as a second situation is the non-symbolic interaction with the virtual world.

It is necessary to clarify that the knowledge that an individual acquires of the world, is obtained in two different ways, the first is with the daily interactions with the world and is known as direct knowledge and often does not realize that it has been learned, the second way in which you can learn is described by someone else, this knowledge is indirect and can always be perceived as this knowledge is taught, the first type of knowledge acquisition will be called as "first person" and the second as in "third person" [13].

The acquisition of knowledge in a natural way is referred to the experiences in the first person and arise as already said, from the direct interaction with the world that in this case represents virtual reality.

A common system used in the computer without more interfaces than the keyboard, the screen and the mouse, does not allow to overcome the barrier of knowledge acquisition in the third person, generating a large gap between the user and the knowledge within the computer. Immersion will be responsible for less to greater extent to overcome this barrier to deliver a more natural knowledge acquisition. It should be noted that the knowledge commonly acquired in schools is in the third person [13].

4.3. Serious Video Game

When talking about a videogame, it usually refers to a program that is used to waste time or keep entertained at leisure, while the word serious represents the opposite, responsibility to focus or pay attention to the actions that we are doing and therefore it seems that the combination of these two words does not make sense.

However, this name was given to videogames or simulations that aim to train or transmit knowledge to users or perhaps just inform.

The main characteristics that define serious videogames are [14]:

- Its objective is education, the training of skills, the understanding of complex processes, which may be social, political, economic or religious or perhaps to advertise products or services.
- They are linked to the phenomenon that is intended to represent, to favor the user's integration with the virtual environment
- Constitute a virtual environment that is plausible for interaction with abstract concepts, in this case mathematical (quadratic surfaces).
- There are interests in its content (political, educational, psychological, etc.)

One of the essential parts that provide serious video games is the feedback mechanism, which refers when the user plays the game or the level repeatedly, until achieving objective knowledge. One of the aspects that characterizes this type of video game is that of voluntary action by users, since most of them are part of an activity to complete a training.

In the videogame the creation of a module called tutorial was made, in which you can perform several practices concerning the concepts of quadratic surfaces, which includes a three-dimensional view of the quadratic

surface, the representation of its mathematical model and its traces in the different planes, within which you can see the different ones.

5. Methodology

For the videogame development, the agile methodology based on prototypes was selected and applied [15], since the basis of the design of this work focuses mainly on the user-centered approach. This technique consists in rapidly gathering specific information about the users' requirements, starting from well-known instruments with observation, interviews, etc.

The prototypes as such, do not have a definition, but depend on the specific situation where they will be implemented. Within them, there is the prototype of patches that consist of the generation of prototypes that focus on functionality, and may lack features or contain errors, but they serve to help the user to evaluate the interface and interaction with the system, errors and limitations are corrected from the information provided by the users, obtaining a complete system when finishing with the evaluations and the patches [15]. In the research prototypes were used per patches.

We worked with the following guidelines to create the prototypes:

Work with manageable modules.

It is about making prototypes that contain the key features of the system, leaving aside the least important ones, so that they can be tested by users and in this way be able to correct important parts and not wait until the creation of the complete system.

Create the prototype quickly.

It is necessary to create prototypes quickly as it is a fundamental part of this approach.

Modify the prototype.

They must generate prototypes that can be modified and therefore are highly independent. Each new modification entails a new evaluation.

Emphasize the user interface.

Must be able to perform all tasks and interact in a straightforward way with the user, since for users the interface is the system and should not be considered as an obstacle

Throughout the development of the project the main characteristics of the proposal were defined, which were: a simulator that shows the quadratic surfaces that were selected by the experts and their respective interaction systems, which were tested in different prototypes, evaluated and improved by adding new features as patches. On the other hand, the videogame module with its main mechanics, as were the rules that define the game mode, life systems, points system, information storage, victory conditions, which were also tested every prototype until the version is achieved. preliminary, to then integrate everything within an application that contains the two proposed modules. A third element, which shows the performance achieved by the user during his game and his level compared to other players.

The objective of the proposal was to promote the user to recognize the relationship between the mathematical model and its graph in R^3, for which a system must be carried out that would take care of real time control over the mathematical model and the graph in 3d It was decided that the application be divided into two main modules, the tutorial and the video game.

The tutorial is a module within which the user can perform a series of activities that bring him closer to the theoretical part of the mathematical concepts addressed, while in the videogame module, the knowledge acquired in the module is tested. tutorial. When a player finishes his game, as a feedback, a rating bar appears, so that the user can see what is the current level of knowledge and a table that shows where the user is located compared to other players. In addition, the interaction with the application was developed in a more immersive way than just using the mouse and keyboard, this with the intention of observing whether immersion in virtual reality favors the user experience.

The first activity was to identify and characterize the problems presented by students in the concepts related to the three-dimensional graphics, this activity was carried out by the experts and based on an analysis of the results obtained, the concepts that would be incorporated into the videogame, semiotic representation records that would be included, as well as the didactic part. Later, the video game was designed and developed.

It was decided, in accordance with the user-centered design methodology, to separate the development of the videogame into two modules. A work plan was designed to carry out the programming of each module that would integrate it. The modules were subjected to a series of revisions, carried out by the target user and the expert in mathematics until they met the didactic requirements and the user's experience. Once the design cycle of the modules was completed, they were evaluated by means of several instruments: a workbook, a usability survey, a post-game evaluation, a session using the think aloud method to evaluate the usability of the system.

Because of a series of evaluations, a preliminary proposal of the video game was achieved, which was submitted to an evaluation by the users, and in this way with the collection of the information, it would account for the achievement of the objectives set.

6. Results and Conclusions

To contextualize the application and evaluation of the proposal, it is necessary to clarify that the entire process was developed from the user-centered design scheme. The staging was developed in two moments, with two groups of students with different academic characteristics.

The first group consisted of three students from the third semester of the computer systems engineering career. The main characteristic of this first sample was that the three have different academic attributes and were selected by teachers from the Technological Institute of Ciudad Guzmán that teach the subject of vector calculus. The selection criterion was based on their academic skills, being three categories: high, intermediate and low. The reason for this decision was to observe the performance of the game with users with different learning skills and contrast their achievements.

In the intervention, three data collection instruments were used, the first consisted of a work notebook designed

by the experts that served as a link between the player and the tutorial module section of the video game. This material contains strategically designed activities to focus the user's attention on the essential elements of the concepts treated, so their interaction with the tutorial was not hazardous. They read some general aspects of the quadratic surfaces and then interacted with the tutorial module to obtain information on the progress of the users [16].

The proposal was implemented with the students mentioned above, two aspects were observed in his intervention: the usability of the videogame and the learning achieved with it. For the first one, the Think Aloud technique was applied for the evaluation of the interface, mechanics and interaction of the video game in its entirety, including the two modules. To investigate the lessons learned, an instrument designed by the experts was applied, which consisted of a printed document with a series of questions in which the user had to identify the graph of a surface and relate it to his mathematical model.

The Think Aloud method was applied in the following way: as the immersion sensor was the Kinect which reacts with gestures, the user was explained in what those gestures consisted for the interaction with the videogame while familiarizing himself with the gestures. Later, he started his departure and was asked to express aloud all the ideas that would pass through his mind during the interaction with the system and the observer only interrupted the moments of silence with the onomatopoeia of clearing his throat, this for avoid influencing the information generated by the user, since any use of words can influence the information that the user would have intended to communicate. These sessions were videotaped to avoid corrupting the information generated by users as much as possible.

For the second evaluation of the game was made with two students who have very different characteristics. One of them recently admitted to the Technological Institute of Cd Guzmán, the engineering career in computer systems and the second of the ninth semester (he is about to graduate) from the career of electronic engineering. We sought to investigate their academic characteristics as background to describe their academic achievements. The contrast was evident, since the new entry did not yet have much knowledge in mathematics at the university level and the other user had successfully completed and accredited the six compulsory mathematics subjects offered at the Technological Institute of Cd. Guzmán, but that in the classroom he did not deal with the concepts that quadratic surfaces entail.

The purpose of this choice was to observe and describe if the videogame promotes skills and learning in students totally unrelated to the subject and in contrast to their academic position, describe its effects on the development of skills in a student who has learned in the traditional way concepts mathematicians (explanations on the blackboard). As these users turned out to be significantly different curricular, it was decided to conduct an in-depth interview. The specific purpose with this interview was to know some academic characteristics that would allow to dimension with greater perspective the abilities of the subjects and to determine what was the impact of the videogame in said players. The results of the students' scores after using the videogame are shown in Table 1.

Table 1. Results obtained by users in the post test application using the video game in the last evaluation of the software

Student	Number of successful items
low	7/13
Intermediate	8/13
High	13/13
First semester	13/13
Ninth semester	9/13

It can be observed in the table that the academic background was not significantly relevant for the construction of learning, the students progressed satisfactorily and motivated by immersive experience. Regarding the interaction of the user with the developed environment, it was observed that the students did not present difficulties when viewing three-dimensional models within a virtual world, since when the evaluation of each design stage was carried out and later, when the beta version was evaluated of the game, the environment did not cause any discomfort such as dizziness or any inconvenience and even when manipulating, rotating or moving the video game camera.

On the other hand, the immersive environment through gestures through the Kinect sensor, motivated some players to study the concepts treated, being more pleasant the learning experience with respect to simply interacting with the mouse and the keyboard. This was somewhat controversial, as some users, who had had some relationship with sensors or controls similar to the Kinect, found it nice to be able to control the application from the Kinect, while other users who had not had any relationship with this type of interfaces they found it difficult to interact with the Kinect and preferred to control the application in a more conventional way with the keyboard and the mouse. However, when they interacted with the videogame, it was shown that students can understand the relationship between the parameters of the mathematical model and how to change their three-dimensional model, regardless of the interface.

On the other hand, the immersive environment through gestures through the Kinect sensor, motivated some players to study the concepts treated, being more pleasant the learning experience with respect to simply interacting with the mouse and the keyboard. This was somewhat controversial, since some According to the data collected, it was observed that the proposal promotes learning, since the scores obtained by the players and the results of the written evaluation account for it. One of the most important achievements obtained in the fieldwork was that the students understood the changes that arise in the mathematical model when the graph of the surface changes orientation. The users were able to learn two representation registers of the same concept, by establishing the relationship between these two registers. This was observed when the two registers were manipulated at the same time and the user was able to notice the changes in real time, so it can be affirmed that learning was achieved, as mentioned by Duval [12] when a subject manages to move from one record of representation to another of the same concept, the subject has acquired a domain over this.

Up to the stage in which the video game is presented, positive results are obtained satisfactorily with respect

to the acquisition of knowledge by the user, but it is kept in mind that its functionality must be extended and redirected towards more didactic purposes, for example incorporating all the lessons referring to the quadratic surfaces and also provide a report of the failures that the user has in the learning process, and that the same video game makes suggestions regarding the conceptual points that the user should study more in depth.

It is concluded that it is necessary to continue evaluating and enriching the videogame in scenarios where more students participate to evaluate their impact on the learning of quadratic surfaces. It is also suggested to conduct a study with more players following the user-centered methodology, which was satisfactory that the game was designed based on the needs of users, since given the nature of the software it is very difficult to design a video game that promote learning without being considered the end user.

In addition, when the environment designer approaches the needs of the user, he develops an environment that caters to different learning styles and needs and can consider which instruments to incorporate, since not all of them favor the same technologies as the immersive, for example. This is because it was evident that, for some users, who had not had contact with immersive technologies, it was difficult to initiate the interaction for the acquisition of knowledge. Perhaps if in the future we intend to apply a videogame to promote learning at a massive level, it would be more feasible to use a more common interface for users instead of looking for a more natural one, but that virtual reality is a tool of great importance to the Explain concepts in the three-dimensional Euclidean space, since it allowed users to visualize all the changes in real time, something that is impossible for a teacher on a blackboard.

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