Virtual reality application for learning geography with gesture interaction

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ABSTRACT
Geography class lessons should adapt to new technology to improve teaching and increase student motivation. To enhance teaching experience, teachers can start with a map or globe presentation, followed by images and videos about the topic. However, organizing the lesson can be time- consuming, causing students to struggle when studying alone, thus the solution is to create a VR application such as GeoJoc. This application will provide information about rivers and mountains and include a quiz to test understanding. The immersive 3D world in GeoJoc will represent information through images and videos, enhancing interactivity, allowing users to interact with objects in the game using their hands and to perform actions with hand gestures. The key aspect of the game is to increase kids' motivation, attention, and understanding.

Author Keywords
Virtual Reality; Meta Quest 2; Mountains and river lesson; Quiz; Educational Application; Hand Gestures Recognition; Object interaction.

ACM Classification Keywords
Human-centered computing: Human computer interaction (HCI); Interaction paradigms; Virtual reality

General Terms
Virtual Reality; Head-mounted display

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INTRODUCTION

The desire to offer a captivating experience in video games has led to significant improvements in this domain, with 3D games supplanting 2D games over time and virtual reality (VR) games now being widely used for an immersive and realistic perception of the environment [12][17]. Using a VR headset, users are transported into a virtual world generated in real-time, where they experience auditory, visual, and tactile stimuli, making VR a journey that engages hearing, sight, and touch to explore a scene, as noted by Himani Mittal [8].

Technology is expanding, leading to the appearance of VR in many fields such as the military [3], education [16], medicine [13], and agriculture [11], where people view these realistic experiences as games that are useful for learning and participating in simulated activities in dangerous places [12]. The main reason to use VR games instead of 2D or 3D games is to improve memory and attention for users, which happens after they have played the same game in these three types of environments. VR games in education significantly impact learning by motivating students through 3D worlds and objects, organized information, and interactive experiences [8], thereby enhancing traditional teaching methods.

Additionally, these games provide teachers with valuable opportunities to engage students and effectively organize lesson content [7].

GeoJoc is the result of our research work, a VR game designed for 7th-grade geography students, featuring two main components. The first part allows users to explore mountains and rivers on Terra for learning purposes, while the second part involves a quiz to assess understanding, with immediate access to quiz results upon completion. The application runs on the Oculus Meta Quest 2 VR headset, allowing users to use their hands for interaction, thus disabling controllers, in order to directly engage with virtual objects, in an approach to enhance attention, motivation, and enjoyment among users during gameplay.

The entire work represents a full application which can be used in scholar space, this application was developed to be used by students for learning new information using VR games. Also, this project is a good start for introducing technology into the learning process. The focus of this developed application was to create a way for students to learn geography in a different and fascinating environment offered by the VR headset Meta Quest 2. Another point of interest followed during our work was to establish the structure of information which will be used in the learning lessons and search the method appropriate for the evaluation part.

The following sections will present the application, the implementation, technical information, and, at the end, it will describe the testing part.

RELATED WORK

Virtual reality in education

As described in [4], software and hardware's advances have made virtual reality better, with a direct impact in education. Recognizing that children are increasingly drawn to images and internet videos, schools are enhancing their teaching methods by incorporating multimedia content tailored to each lesson. According to [2], integrating VR and multimedia can enhance digital skills and learning strategies, catering effectively to the current generation of students, by utilizing 3D objects in virtual environments. These methods not only increase interactivity and attractiveness of information, but also promote multidisciplinary learning, as noted in [4].

Certain school activities, such as practical experiments in chemistry labs, are deemed unsafe for students due to risks associated with materials or the need for heightened attention. To address this issue, virtual experiences offer a safe alternative environment that facilitates learning from practical activities, as highlighted in [4].

Current Applications

In recent years, developers have created VR applications across diverse fields, including educational games where players traditionally used controllers for interaction. However, advancements now allow users to interact directly with virtual objects using their hands, facilitated by technologies like the Leap Motion controller in conjunction with VR headsets. Moving forward, we will explore notable geography games and highlight those that incorporate hands-on interaction. The three apps described below were relevant for our project because they were a starting point for our activity.

MaxWhere [2] is a VR game focused on educating users about Hungary's Balaton River through structured information presented via images and text. This game emphasizes knowledge evaluation, enhancing geography skills, fostering critical thinking, and promoting analytical attitudes, as noted in reference [2]. This application was very important for our decision to include information about rivers such as multimedia elements, as well as providing a good reason for us to develop an educational VR application.

In [9], researchers advocate for enhancing user interaction in VR games by utilizing the Leap Motion controller to simulate assembling a robot. This involves wearing a VR headset and using the Leap Motion sensor to track hand movements, translating them into gestures that manipulate objects within the virtual environment. Their study demonstrated significant improvements in learning efficiency, particularly in memory retention and problem- solving abilities, as users successfully assembled a robot using 14 pieces relying solely on prior knowledge, as detailed in [9]. Following these advantages for VR interaction and objects in the immersive environment and direct user's interaction using hands we decided to use interaction in our game, but without the Leap Motion sensor and VR headset controllers.

GeograVR [5], developed by Meta, is a virtual reality application where users orient themselves in space and place a pin on Earth's Globe corresponding to a given label. It assesses response time to determine a score, making it a potential tool for evaluating students' geographic knowledge in educational settings. After analyzing this application, we found a proper method for the learning part, more exactly, we added a globe with pins which indicate the rivers or mountains that can be learned by students. Not least, we understood the importance of evaluation knowledge using a VR game.

With help of this existing applications, we were motivated to in introduce a new approach for developing an educational game with interaction using the hands, but the newly part introduced by us were hand's gestures as the method of interaction for learning and evaluation of geography lessons.

THEORETICAL FOUNDATION

The focus of this project was to devise a new interactive approach for developing a geography learning and assessment app. We created a VR game where users engage with scenes using gestures and interact directly with 3D objects, while ensuring lessons and quizzes are highly interactive and enjoyable.

The most important objectives when creating this project were:

- Give up the use of controllers from the VR headset Oculus Meta Quest 2 for interaction.
- Use hand tracking, by way of receiving information about the presence and position of the hand via the four cameras on the VR headset.
- Recognize users' hand gestures and use them for actions in the 3D scene.
- Interact with the virtual objects using the user's own hands, which trigger events during the game.
- Split the application into four modules: two for learning the most important mountains and rivers of the world, and two for checking on these topics.
- Create 3D models representing the Earth Globe, adapted for each module. The module for the rivers topic will feature a 3D globe containing the rivers' locations based on the continents where they exist in real life, locations that will be marked by a pin. The same logic was adapted for the mountain's scene.
- The learning scenarios involve choosing one pin from the Earth globe by touching the pin using the index finger. Following this gesture, users can access the information and navigate between it using other predefined gestures. The available information will

contain pictures and videos that correspond to the selected pin.

- For quizzes, the user will have to respond to 11 questions and will choose the correct answers by touching the objects that correspond with the answer options.
- Since feedback is very important, it should be incorporated in the evaluation process. After selecting an answer, responses will be checked right away, using specific sounds and colors to indicate if the answer is correct or not.
- Users in the VR game can review the results from quizzes, which includes the date of completion, to track their learning progress.

Hands detection

In VR applications like those described in [1], accurate detection of users' hands is crucial for creating corresponding virtual hands that mirror real-time position and orientation. This detection relies on the four monochrome cameras integrated into the Oculus Meta Quest 2 headset. The process involves capturing specific points from the headset's images, detecting hand shapes, and reconstructing them as 3D objects within the VR environment, as detailed and illustrated in Figure 1 and summarize below:

- *Hand Detection*: in this stage, the cameras will retrieve the images from the real environment and will identify the user's hand regardless of the elements that surround it.
- *Hand Keypoints*: after the user's hand is identified, the 19 joints (keypoints) of the hand will be located.
- *Model-Based Tracking*: the keypoints are important for determining which is the hand's position in space. Also, the tracking of hands is supposed to detect movement of hands by tracking the motion of keypoints over time.
- *User Application*: this stage refers to displaying the virtual hands in the virtual environment, having the same position as the real hands.

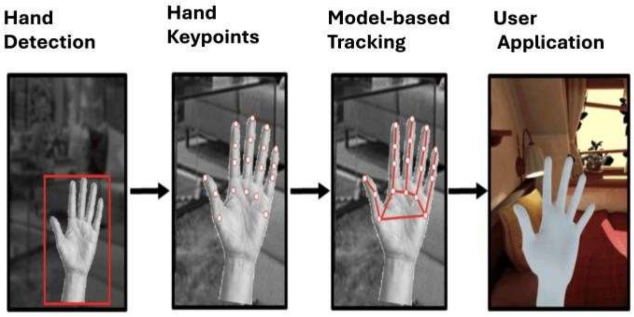


Figure 1. Hand detection process [1].

Gesture recognition using deep neural network

The Meta Quest 2 VR headset utilizes deep neural networks and algorithms to detect hand gestures, predicting joint positions and reconstructing virtual hands from environmental image data [6]. The research paper [1] analyzes the detection accuracy of the described algorithms, reporting a fingertip detection error of 1.1 cm and an average finger joint angle error of 9.6 degrees.

Gesture detection

Custom hand gestures in virtual environments rely on predefined finger positions of virtual hands, as detailed in Figure 2 [6], where multiple shapes are assigned to individual fingers to accurately define gesture shapes during detection.

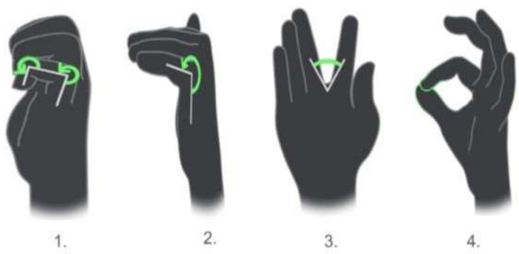


Figure 2. Hand gesture detection: 1. Curl, 2. Flexion, 3. Abduction, 4. Opposition [6].

DESIGN AND IMPLEMENTATION

Product perspective

GeoJoc is a learning game that uses hand gestures, which are very important for interacting in a virtual reality game. Figure 3 shows all important elements necessary for using the application and loading it on the VR headset Oculus Meta Quest 2:

- *GeoJoc Application*: contains Assets with game objects, the package Meta XR Interaction SDK, responsible for interaction via hands and the component OVRCameraRig which corresponds to the camera and hands in scene.
- *XR plugin management*: plugin used in Unity and needed to develop compatible VR applications.
- *Open XR*: is a mandatory plugin, with the main role of rendering the scene from Unity in a VR headset. Also, it has an important role in retrieving the input and information about users' hands.
- *VR headset Oculus Meta Quest 2:* is the hardware that mounts on the user's head and immerses the user into virtual reality. The user can see the environment via two displays which are in front of the eyes. Also, the VR headset has four monochrome cameras that perceive information from the real world, for example, the hand's position.
- *User's hands:* are detected by the cameras and allow interacting with the 3D world and objects through predefined gestures.

- *JSON file:* is the file which stores information about users' progress and quiz scores.

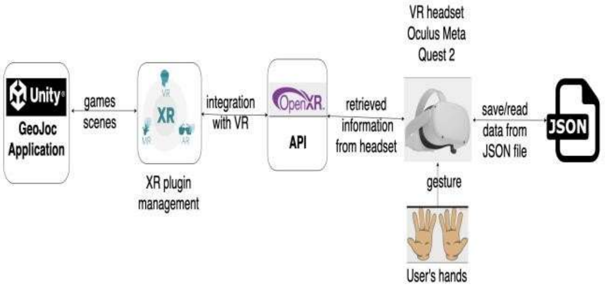


Figure 3. System architecture.

Use cases

GeoJoc has four important functionalities: learning, evaluation through quizzes, register or login and help information. More details about these features can be found in Figure 4 and are also described below:

- *Learning*: This use case involves accessing 12 pins on the Earth Globe to display information, including images and videos of mountains or rivers, with users navigating between content using specific gestures.
- *Quiz*: The application includes two separate scenes featuring questions about mountains and rivers, where users must select answers for 11 questions. Interaction involves directly interacting with objects representing answer choices, with selection confirmed upon touching the object corresponding to the correct answer. Responses are instantly validated through visual cues and auditory feedback, such as specific colors and sounds indicating correctness or incorrectness.
- *Login/Register*: Users input their name by directly interacting with a virtual keyboard using their index finger, enabling immediate access to learning lessons thereafter.
- *Help Menu*: A feature through which the user will access information about the available actions from each scene.

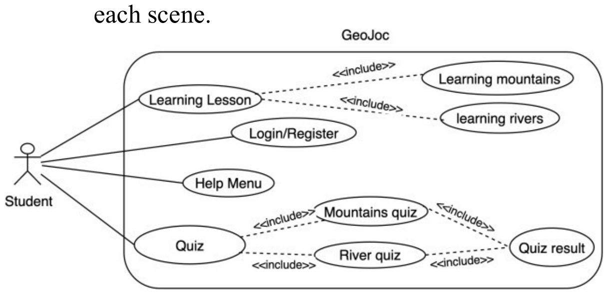


Figure 4. Use case diagram.

Scene structure

The project is organized into separate scenes, each featuring essential components such as OVRCameraRig and scene-specific objects. For instance, the scene dedicated to learning about mountains (as seen in Figure 5) includes elements like LeftEyeAnchor, RightEyeAnchor, CenterEyeAnchor for visual environment rendering, LeftHand and RightHand for virtual hand identification, and a learn_mountains object containing 3D models of mountains, Earth Globe, videos, and images for the learning module. Similar objects are utilized in other scenes with specific content variations.

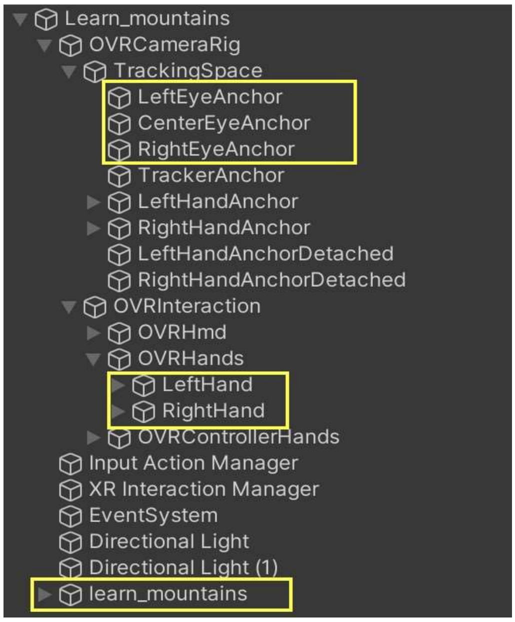


Figure 5. The Structure scene for learning mountains.

Building a gesture

In GeoJoc, users use four gestures to trigger different actions based on the scene they are currently navigating. These gestures are:

- *One finger visible:* index finger.
- *Two fingers visible*: index finger and middle finger
- *Four fingers visible*: index finger and middle finger, ring finger, little finger.
- *Five fingers visible*: thumb, index finger and middle finger, ring finger, little finger.

In what follows we will illustrate the process for building the gesture which represents two fingers visible. The most important part is creating an object of type Shape Recognizer, available in Unity in the Shape Detection subsection of the Oculus section. As can be seen in Figure 6, for each finger we have to select the desired features for specifying the shape used to define and identify the gesture. For each finger, we choose between 'Is' or 'Is not' verbs, then, we use one or more finger positions to describe the finger shape, for example: Nothing, Everything, Curl, Flexion, Abduction, Opposite. All new gestures will have a Shape Recognizer adapted for the new position of the fingers which define the gesture.

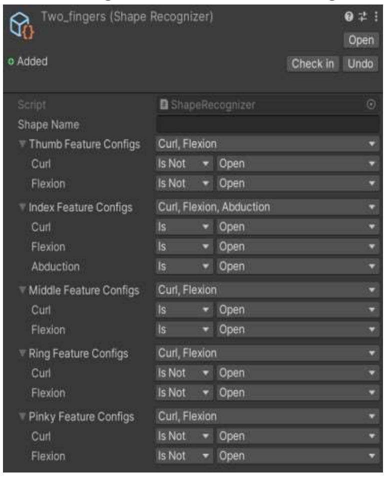


Figure 6. Configuration of Shape Recognizer for a gesture with two fingers visible.

For each gesture, the features of each finger that forms the gesture can be consulted in the tables 1, 2, 3:

Table 1. Shape Recognizer for detecting index finger

Finger	Feature Configuration	
Thumb	Curl & Flexion	Is not Open
Index finger	Curl & Flexion	Is Open
Middle finger	Curl & Flexion	Is not Open
Ring finger	Curl & Flexion	Is not Open
Pinkey	Curl & Flexion	Is not Open

Table 2. Shape Recognizer for detecting index finger and middle finger, ring finger and little finger.

Finger	Feature Configuration	
Thumb	Curl & Flexion	Is not Open
Index finger	Curl & Flexion	Is Open
Middle finger	Curl & Flexion	Is Open
Ring finger	Curl & Flexion	Is Open
Pinkey	Curl & Flexion	Is Open

Detecting a gesture

After establishing the finger shapes which define a gesture, the next step is to create a new Game Object with scripts needed for detecting the gesture for a specific hand. The entire application will use this new object and will attach it to different scripts to detect gestures in game scenes. The most important observation is that each Game Object will be configured with one specific gesture that will be detected just for the hand which was added in a specific script for this object.

Table 3. Shape Recognizer for detecting presence of all fingers

Finger	Feature	Configuration
Thumb	Curl & Flexion & Abduction	Is Open
Index finger	Curl & Flexion & Abduction	Is Open
Middle finger	Curl & Flexion & Abduction	Is Open
Ring finger	Curl & Flexion & Abduction	Is Open
Pinkey	Curl & Flexion	Is Open

The full configuration for an object which will be used in game scenes for detecting the gesture with two fingers visible can be consulted in Figure 7. The explanation for each attached script is described below:

- *Shape Recognizer Active State*: the gesture that is to be detected, which is an object of the type *Shape Recognizer* should be selected for the attribute *Finger Feature State Provider*.
- *Hand Ref*: this script will specify the hand to which the detected gesture will be attributed to.

For each of the four gestures that are used in the application, the scripts are similar. What differs is the hand for which the gesture is detected and the gesture itself.

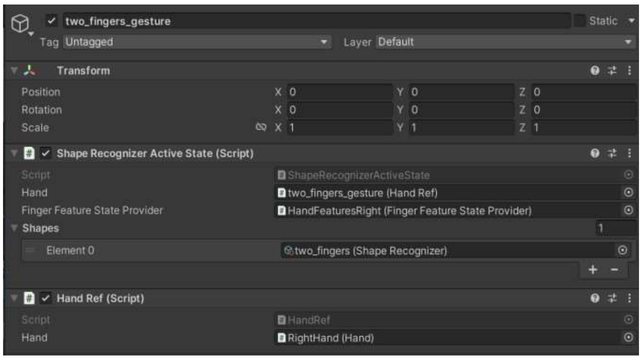


Figure 7. Configuration of a Game Object for detecting a two fingers gesture with the right hand.

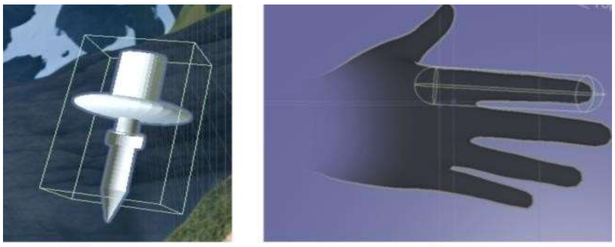
Accessing information and navigating between them in the learning level

To access information about mountains or rivers on the 3D globe, users touch the corresponding pins with their index finger. Each pin represents a specific geographical feature located on the continent displayed on the 3D globe (Figure 8), enabling direct interaction through colliders assigned to the user's finger and the pins, as detailed in Figure 9.

Following the detection of the collision between the index finger and the pins on the globe, text information, videos and images about the element that the pins marks will appear in the scene, like illustrated in Figure 10.

a. b.

Figure 8. Pins on the 3D globe that mark the mountains and the rivers (b) that can be learned.



a. b.

Figure 9. (a)Box Collider and Tag specific to each pin. Adding Capsule Collider for the index finger with which it will interact with the pins.

a. b. c.

Figure 10. Information in the form of (a) text, (b) image and text, (c) video.

The logic for navigating through information using gestures

After pressing the desired pin, the user will see the first information about the selected item. To navigate to the next piece of information, it is required to perform the gesture consisting of the index finger visible with the right hand. To return to the previous information, the same gesture will be made, but with the left hand. To view videos or images, the user will use the gesture made up of 4 visible fingers: index, middle, ring and little finger.

For example, the user will be able to manipulate information as in Figure 10 (b), through the script 'Next_previous_image' which is available in Figure 11. In this script, Selector1 and Selector2 are the gestures which will be used for visualizing the next and previous image. The images and corresponding text are added in section 'Images' and 'Description.'

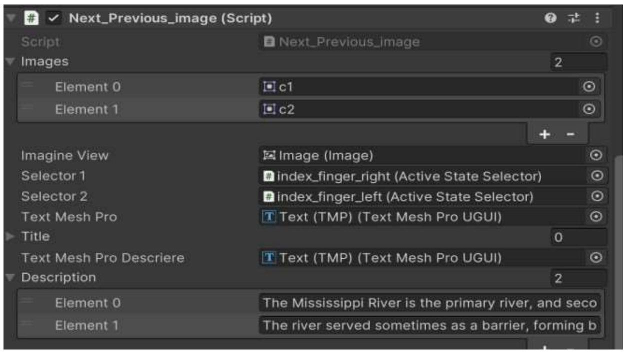


Figure 11. The script to visualize the following or previous image using the index finger from right or left hand.

Quiz evaluation module

After reviewing all the information at a learning level, the user can test their knowledge with 11 questions, each question offering 3 possible answers. The steps to select a response are:

- display selectable answers using the gesture with 5 visible fingers of the left hand.
- press the letter A, B or C corresponding to the correct answer, using the index finger from right hand.
- confirm the answer using a specific button

After selecting an answer, the system automatically validates it, providing visual and auditory feedback based on correctness. Correct answers change the selected letter and question image to green, as shown in Figure 12.

a. b.

Figure 12. (a) Selecting the answer 'A'. (b) Validating the answer as correct.

In case of incorrect answers, the feedback displayed (Figure 13) shows the selected letter changing from purple to red, while the correct answer's letter turns green.

a. b.

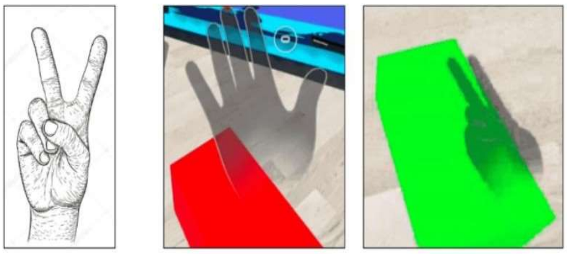
Figure 13. (a) Selecting the answer 'C'. (b) Validating the answer as wrong.

There are specific sounds for right or wrong answers and after 3 seconds, a new question will be available.

TESTING

Functional testing

Functional testing was employed to monitor user interaction behavior within the scene, while unit testing was utilized specifically for gesture detection. Each gesture was individually tested by adding a test cube to the scene, which transitions from red to green upon successful detection of the gesture (Figure 14). The 'SelectorDebugVisual' script [14] facilitates the configuration of which gesture to detect, the target object for color change, and the specific colors applied to the object during testing.



a. b. c.

Figure 14. (a) The gesture that will be detected. (b) The gesture is not detected. (c) The gesture is detected.

Non-functional testing

Performance testing was done using the OVRMetricsTool [10], and the results for the learning module can be consulted in Figure 15. During this test scenario, it is visible that scene transitions initially caused a drop in FPS to 40, recovering to 72 after loading learning content, while interactions with pins on the globe briefly reduced FPS, returning to normal upon loading learning objects, also the CPU usage had value equal with 34% and the precent of GPU usage was 68%.

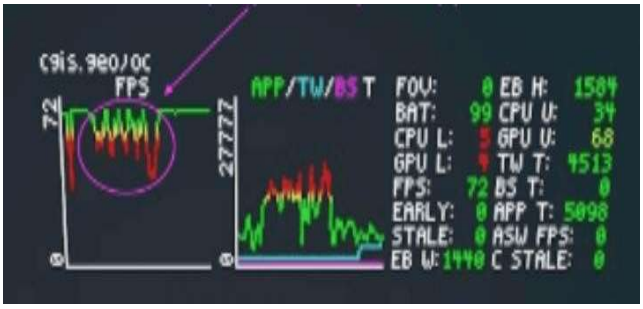


Figure 15. Moving from the starting module to learning mountains and accessing pins.

User Testing

The application was tested by three 8th-grade students to assess their reactions to the VR learning game, focusing on their engagement with gestures, direct interaction with objects, and their perception of instant feedback, evaluating whether this learning method was enjoyable for them. Although the application was created for 7th-grade where students are between 13-14 years old, the app was tested with students from 8th-grade who were 14 years old, so the age limit was respected, and the knowledge was appropriate for both groups.

In the scholar space, during the testing GeoJoc application, the entire activity was organized in two parts: a demo of the application, followed by the students' own experience. In the first part the game was played by another person, the gestures and actions in the game were presented, and the rules of the game were explained. All students were seeing in real time all gestures and the game, through VR headset casting. After this presentation of the game, three students played, one by one the game and support was offered when they need help regarding the rules and gestures allowed within the game.

To analyze the students' feedback, after the end of the game, they filled out a questionnaire that can be consulted in Table 4. As can be seen in question 5 of Table 4, the interaction through gestures was loved by students; more precisely, the gesture made with the index finger was considered the easiest to use. At the learning level, all students found that images and videos are useful for learning (the question 8 can be consulted), and the pins on the globe help them detect the location of the content on which the selected item is located (see question 9). The quiz part was considered useful and helps to learn from mistakes. Instant feedback helps to quickly find out the correct answer, as can be seen in question 10.

CONCLUSION

Games are increasingly used in education to convey information in an interactive way that increases the attention and involvement of students. Also, the lessons of learning and evaluation are more structured and easier to understand by students through interactive, educational games.

Table 4. The questions and answers from the questionnaire

Question	Number of responses	
1. How much experience do you have with VR games?	3 students	No experience
2. What feelings do you get when playing a VR game?	3 students	Very pleasant feelings
3. How easy was it to interact using gestures?	2 students	5/5:Very Easy
	1 student	4/5:Easy
4. How hard was it to use the button interaction on the virtual keyboard?	2 students	4/5:Easy
	1 student	5/5:Very Easy
5. Which gesture was the easiest to use?	3 students	Index finger
6. Which gesture was the hardest to use?	3 students	Four fingers
7. What kind of interaction do you prefer?	2 students	Gesture
	1 student	Touch objects
8. What do you think about images and videos in learning lesson?	3 students	Useful
9. Will the pines on the globe help you in the learning process?	3 students	Yes
10. How did you like the interaction and feedback from the quizzes?	3 students	Helpful

The implemented game integrates learning about mountains and rivers alongside quizzes in a cohesive manner. To enhance immersion, users interact without controllers on the Oculus Meta Quest 2 VR headset, using their hands to perform specific gestures that trigger actions within the virtual environment. Direct interaction with objects like keyboards or globe pins is facilitated using the index finger for a more intuitive experience.

Students appreciate the use of VR environments in lessons, as it enhances their attention and motivation, facilitating interactive and enjoyable learning experiences.

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