# VIRTUAL REALITY-BASED E-LEARNING SYSTEM USING DISTRIBUTED WEB SYSTEMS

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*This paper discusses the creation and implementation of an accessible web interface for a virtual system laboratory, focusing on the benefits it can offer students from disadvantaged backgrounds. The project is addressing digital inequalities and provides a platform to help digital education and inclusiveness for all students. This is done by providing an inclusive educational platform example that helps students with limited access to gain practical knowledge in biology, chemistry, and IT systems. The student's working environment is simulated to facilitate quick and easy access to various skills related to IT, biology, and chemistry exercises using the web interface. The system removes obstacles for students with different needs and facilitates distance learning through the use of useful web technologies and responsive design. We promote equal opportunities in education by offering learning opportunities, regardless of the students' backgrounds. Gaining practical skills in these three areas through such a project gives students opportunities to overcome their condition. The web interface offers a collaborative learning part, which includes the following aspects and functionalities: interactions and exchange of knowledge between students. In addition, this virtual laboratory also has the functionality to be adapted dynamically according to the students' preferences. The system will provide feedback based on the degree of evolution of each individual student. The article studies the aspects of developing such a system within a program and tries to estimate the results and essential characteristics, as well as the anticipated effects of such a system on improving access to different education areas for students.*

**Keywords**: Accessible web interface, Virtual education system, Disadvantaged Students, Inclusive educational technology, Distributed web systems, Remote learning opportunities

## 1. Introduction

Currently, a frequent problem for students, especially those in the field of exact sciences, is the lack of practical skills. Students do not possess the skills that would allow them to apply in practice the theory and research methods learned [1]. These problems are accentuated for high school students from disadvantaged environments (people who come from difficult socio-economic contexts, not because of medical disabilities), having mobility impairments or other disabilities.

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The presence of technology in schools is on the rise. Technology must be present in schools to improve performance and facilitate student-learning methods. The literature covering technology in education has documented an improvement in student achievement if technology is used appropriately [2]. Studies examine how blockchain technology can improve the validation and certification of skills in education, ensuring transparency and security [3]. Academic practices are not limited to content theory teaching and assessment; they also include laboratory activity and experimentation. Some subjects, such as biology, mathematics, computer science, chemistry, and physics, require laboratory activities. For these subjects, the educational institution must provide the necessary facilities and infrastructure to support experimental activities [4]. For example, in fields like chemistry or medicine, performing experiments in the laboratory represents an important step in the learning process. However, they can be dangerous and expensive. Virtual reality (VR) provides a safe and cost-effective way to conduct experiments. Students can perform complex chemical reactions, observe molecular interactions, and analyze without the risks associated with handling hazardous materials. In medicine, VR can be used to create highly realistic medical scenarios where students can practice procedures, make diagnoses, and take critical decisions in a risk-free environment. By not completely replacing physical training, VR can reduce the risk of students damaging expensive equipment or wasting various materials used in hands-on learning, making high-quality medical education more accessible to a wider range of institutions and students. VR also provides an opportunity for constructive learning, allowing students to construct their own knowledge through experimentation [5]. For example, students can learn more about astronomy by learning to build a 3D model of the solar system [1]. VR is essential to maximize experience and knowledge assimilation [5]. It offers a chance for constructivism to increase interactivity and have an impact on the student's personality, encouraging creativity [6].

This article aims to investigate a series of essential indicators that reflect the impact of developing and implementing an educational platform based on virtual reality and distributed web systems on the learning process. The specific objectives pursued include increasing knowledge retention, improving the user engagement rate, optimizing learning efficiency, increasing user satisfaction, reducing the frequency of errors during interaction with the application, and ensuring a high level of accessibility for all categories of users, especially those from disadvantaged backgrounds or with special educational needs.

## 2. Literature Review

An article by L. Freina and M. Ott [7] explores the evolution of virtual reality since the term was introduced in the 1960s, presenting two categories of VR: non-immersive and immersive. It is highlighted that immersive VR, offering a physical experience in non-physical worlds, is becoming more accessible thanks to devices such as the "Oculus Rift". The authors emphasize the high potential of VR in education for motivating and engaging students.

Research by Kavanagh et al. [8] highlights the high presence of virtual reality in education for over half a century, but wide adoption lags due to the multiple limitations of the technologies involved, as well as the high costs and logistics required for their implementation. The authors conducted a systematic review and two thematic analyses to understand the problems and benefits expected by educators when using virtual reality in education.

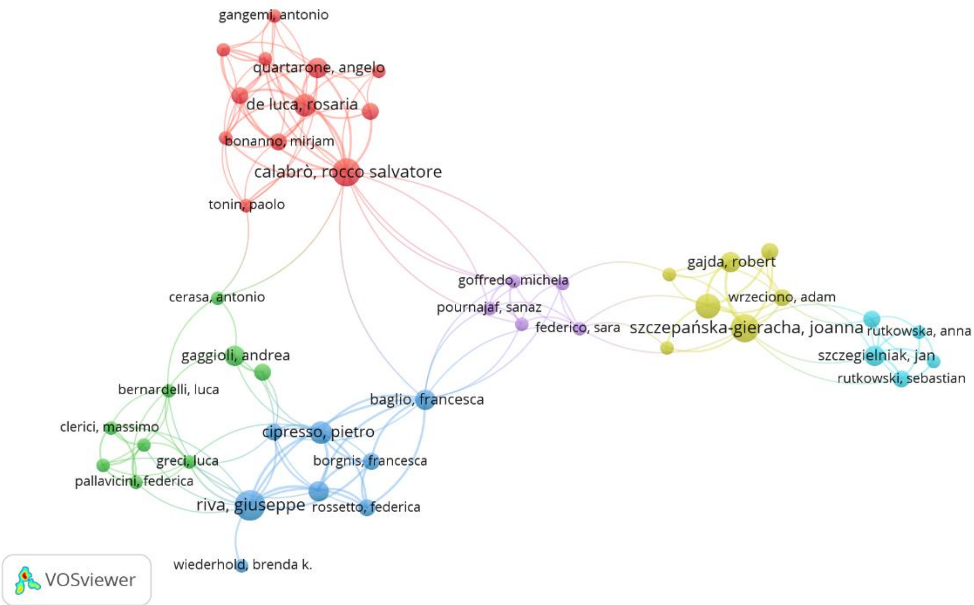


Fig. 1. A graphic map of authors for the search term "education and virtual reality"

Finally, innovative methods to address these issues are proposed, and future directions are indicated for researchers who wish to apply these emerging technologies in education [9]. Daniel W. Carruth explores in his article [10] how the advent of inexpensive consumer virtual reality display technology has opened up new horizons for delivering education and training in immersive and engaging ways. The article points out that the advent of inexpensive consumer virtual reality display technology has opened new ways to teach and learn in an immersive way. These environments can provide access to expensive equipment in impossible locations, providing a space where students can explore problems and test solutions without risk [11].

However, questions remain regarding the capabilities and limits of current technology, particularly regarding the effectiveness of acquiring knowledge and skills in virtual reality. The process of developing effective virtual learning environments begins with understanding learning objectives, recreating real-world tasks, and evaluating user performance and learning. Each step of this process comes with challenges and opportunities [12].

By applying a dynamic analysis method to the subject of education, especially education using virtual reality, the literature provides a diversity of publications signed by a large number of authors. In this empirical investigation, the "Dimensions.ai" platform was used as a database, and its search functionality was used in the search process. The results obtained were analyzed using the VOSviewer Application in order to easily identify authors who published on the topic, resulting in a graph. The identified author cluster represents distinct groups within an author network, as illustrated in Fig. 1. The data set was observed to contain 11784 authors. To be considered relevant, an author had to fulfill the condition of appearing as an author in at least two papers, and that author had to have at least two citations. A total of 1011 authors met these conditions, of which 1000 were selected.

## 3. Methodology

The main purpose of this research is the development of a gamified system that is used by students who come from both disused areas and those who do not have access to a continuous study program, as well as those with special needs. The objectives that this gamified system proposes are the following: the development of interactive games for several areas of study, which will facilitate learning and evaluation of students' performance who use this system [13]. The system was implemented in a distributed manner to function simultaneously within institutions with several physical locations.

To create a more robust and responsive e-learning system, some distributed components can be implemented to enhance performance, scalability, and reliability [1]:

a. Content Delivery Networks (CDNs): Distributing content such as videos, images, and other learning materials across multiple servers to reduce latency and improve access speed for users.
b. Computing Resources: Distributing computational tasks across multiple servers to handle intensive processing tasks required for rendering VR environments.
c. User Data: Distributing user data across multiple databases or data centers to ensure data redundancy and reliability.
d. Services and APIs: Distributing various services and APIs (such as authentication, data storage, and analytics) across different servers to balance the load and ensure high availability.
e. Network Infrastructure: A distributed network infrastructure ensures consistent and stable connectivity for users, regardless of their geographic location.

f. Edge Computing: Processing data closer to the user (at the "edge" of the network) to reduce latency and improve real-time interactions in the virtual reality environment.

From the above-mentioned possible components, we focused on two aspects, the distributed DBMS and load balancers.

The distributed system architecture for the VR-based e-learning platform is depicted in Fig. 2, where user requests first pass through load balancers to nearby edge servers that perform initial processing and caching. From there, proxy servers take over, ensuring secure and optimized data routing before forwarding requests to the origin servers, which host the core application logic and databases. This layered approach improves latency, enhances system reliability, and balances load—key factors for delivering immersive virtual reality experiences at scale.

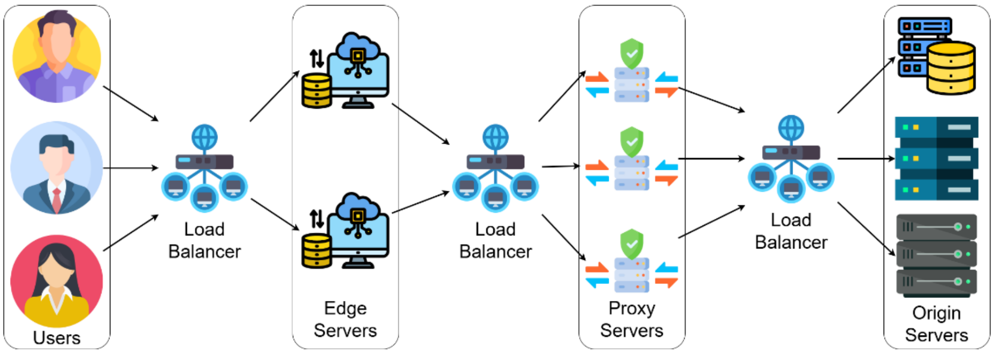


Fig. 2. Distributed System Architecture for VR-Based E-Learning Platform

In this article, a virtual reality application is proposed to assist students with different needs or coming from derelict areas. The application is very much focused on the visual part, the graphics. Thus, the students who use the application will be very attracted to it. The application is built using the Unity game engine. Unity is a multi-platform game creation engine that is used commercially for creating 2D and 3D video games. Unity is used also for interactive simulations [14].

As far as interactive simulations are concerned, different virtual reality scenarios can be created with the help of Unity. They can be used in different work areas, such as medicine, the treatment of various phobias, engineering, architecture, or education. Within the educational area, virtual reality is used to create and simulate lessons in different areas of study. The application is very much focused on the educational side, where students interact visually with the system. Thus, the application will combine both code and graphic and infographic parts. The architecture used by the Unity game engine is called the Entity Component System and is abbreviated ECS. ECS, as represented in Fig. 3, is the core of the Unity Data-Oriented Tech Stack and has three main components: entities, components, and systems [15].

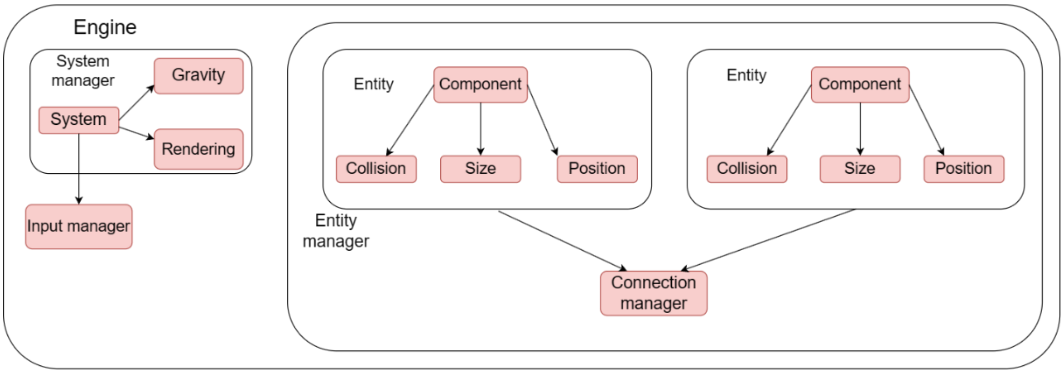

Fig. 3. ECS type architecture

To ensure efficient storage of data used within the application, a distributed Database Management System (DBMS) is a viable and beneficial approach, providing [1]:

a. Scalability due to the ability to handle large amounts of data and user requests, which is essential for a system that may have many users accessing it simultaneously.
b. Data Redundancy and reliability due to data replication across multiple servers.
c. Performance by distributing the load across multiple servers to improve the performance and responsiveness of the system.
d. Flexibility by storing and processing the data closer to where it is needed, thus reducing latency and improving user experience in a virtual reality environment.

Among Apache Cassandra, MongoDB, Google Cloud Spanner and Amazon DynamoDB the selected database was MongoDB. The main reasons were the possibility to have on-premises installations and because in scenarios where data exhibits greater dynamism and lacks a consistent structural framework, MongoDB has been shown to outperform Apache Cassandra.

Another key component for a distributed web system is the load balancer (hardware, software, or cloud-based, such as AWS Elastic Load Balancing, Google Cloud Load Balancing, or Azure Load Balancer). Due to cost, the optimal solution is a software load balancer such as HAProxy, Nginx, or Apache Traffic Server. For a good incoming traffic distribution, Nginx is used to implement a Round Robin method. As a future development, testing online services from Cloudflare, Amazon CloudFront, and Akamai is planned.

Entities are defined by the objects that populate the program and are seen by users when interacting with the system. Components are defined by the data associated with entities in the game. Currently, quite a few game engines are used, with the help of which virtual reality applications are created, namely: CryEngine, UnrealEngine, SourceEngine, and Unity. The criteria for choosing the game engine for this application involving gaming and virtual reality concepts, were the following: easy use of game creation concepts, scenes, character modeling, and, above all, quality graphics [16].

In addition, other very important aspects that contributed to the choice of the Unity game engine were its easily accessible interface, the audio-visual performances, including sounds and animations, accessibility, the programming language used for the code, and composability. We started from the premise that pupils and students, who lack advanced knowledge of virtual reality, will use the application, making the easily accessible interface a crucial element. The audio-visual performances are also a key element for these types of applications because users have the most contact with the acoustic and visual parts during the use of the application [17].

The accessibility of the Unity game engine means that the applications developed with the help of Unity are very easy to integrate on different platforms, and it is very easy to integrate auxiliary devices, such as VR headsets and joysticks. To test this system, we used the Oculus Quest 2 META VR glasses, which also have integrated joysticks [18].

Physics is a very important part of gamified, virtual reality applications. In a 3D system, the objects in the scene must have certain characteristics, namely: speed, which can increase or decrease, and acceleration, which increases or decreases with the change in speed [19]. Another important aspect of 3D gamified games is collisions with the terrain and with different objects, which are also actuated by gravity or speed. Considering that this application is an educational one, which must place the students who use it as close as possible to reality, we chose to create a “first-person controller” type application [20].

The application is focused on the development of knowledge in several areas of study for students who do not have access to education [21]. The development process of this application consisted of the accumulation of concepts from several areas of study that are necessary in the students' curriculum, namely: chemistry, biology, and informatics. Here is the information that students must study in the usual way in the curriculum [22]. The application includes a variety of elements, such as concepts from the subjects covered and the completion of missions in each lesson. In order to move on to the next step, students must complete all the missions related to each level. The missions consist of finding objects that are in the scene and reading their related descriptions. In addition, students must answer questions about what they have studied after completing each individual level [23]. The application is developed upon three main scenarios created within the virtual reality application that come to the aid of students with educational disabilities.

Fig. 4. Main menu of the application

The system presents scenes made in Unity 3D that place users in 3 different scenarios, each representative of an area of study, namely: chemistry, anatomy, and informatics. The subjects that are addressed in the application were chosen due to their importance in the study curriculum. The main interface (Fig. 4) illustrates several functionalities: The "New Game" button allows users to start a new game or reset what they are currently working on.

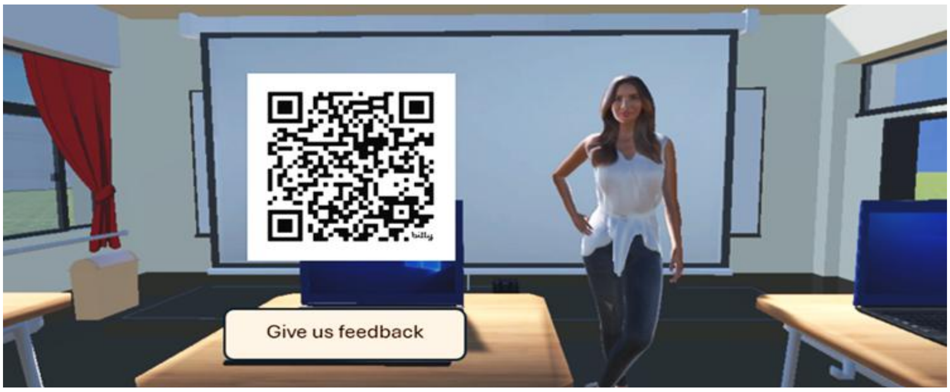

Fig. 5. Feedback

In contrast, the "Play" button allows users to start the game without destroying the progress made up to the current moment. The main interface is accompanied by a "Settings" button, which allows users to make several changes, namely: the sensitivity of the mouse, the intensity of the light, and the sound. The "Feedback" button allows users to give feedback to the application.

Fig. 5 shows the interface with which users can scan the QR code to access the questionnaire form. Because it is an application intended for education, it combines both educational and graphic aspects so that the students enjoy what they learn. It is not a mechanical way of learning but practical and enjoyable [24].

Fig. 6. Student learning about computer components

The application offers users an interactive, very realistic scenario in which students will learn basic concepts about the human body: the bone system, the muscular system, the internal organs, and the role of each of them in the body.

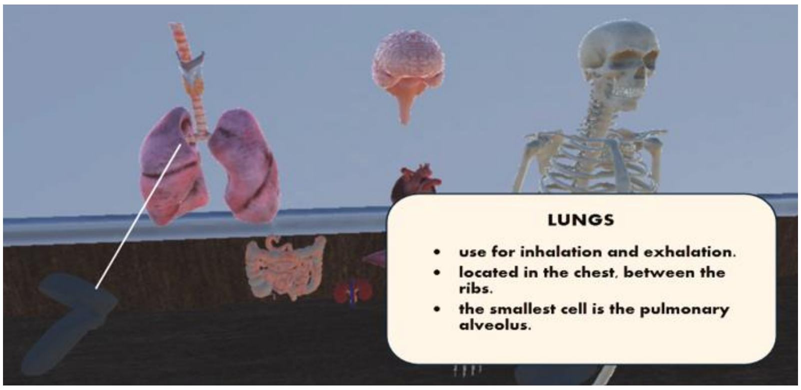

Fig. 7. Student learning about organs – lungs

Students will use joysticks, which are part of the auxiliary equipment, to perform the various tasks and to interact with the system [25]. After completing the second scenario, the user will move on to the third, which is based on IT concepts. Students will learn both software and hardware concepts. One of the tasks the student has to do is assemble a computer, illustrated in Fig. 6, using the components available on the table.

When the student picks up one of the components, the system will provide information about it. As shown in Fig. 7, the user uses the joystick to discover the functionality of the lungs. Students will use joysticks, which are part of the auxiliary equipment, to perform the various tasks and to interact with the system.

In addition to the scenarios that we have presented, we have implemented some in more detail for the deepening of knowledge, in case the students want to insist more: they can learn more advanced things about biology, medical genetics, and learn more detailed elements about animal anatomy [26]. Regarding the chemistry scenario, students can practice their knowledge on complex experiments. Students can do experiments that contain several substances and different materials in order to better understand the phenomena that are inside a chemical experiment. Finally, in the computer science scenario, students can even have lessons on assembling servers in a data center [5].

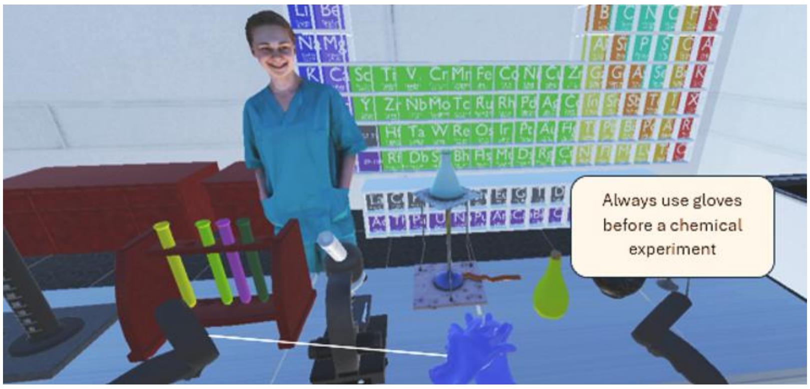

Fig. 8. Student making an experiment

After completing all the tasks related to this scenario, the user is automatically sent to the second scenario, the chemistry one, illustrated in Fig. 8. Students have in the chemistry scenario the most basic part that they will use in the study of this discipline: the periodic table of the elements. One of the tasks they have to do at this level is to recognize and find, in the periodic table, their notations. After completing these steps, the student is invited to perform a simple chemistry experiment in which he will use sodium chloride. It is very important that, during an experiment, students wear protective gloves, a gown, and glasses. Before performing the experiment, the system will warn them about this [27].

Fig. 9 presents the UML diagram of the developed application. The user accesses the application through VR glasses. Once in the application, a list of options with the exercises currently available in the application is presented, and the user is required to choose one of the three exercises (Computer science, Anatomy or Chemistry). After selecting the desired exercise, various virtual tools will appear to solve different tasks. A task once solved correctly leads to a new task, and if the first task is not solved correctly, it remains at this one until it is solved correctly. Once solved correctly, the user is redirected to the screen where the achieved performances are indicated.

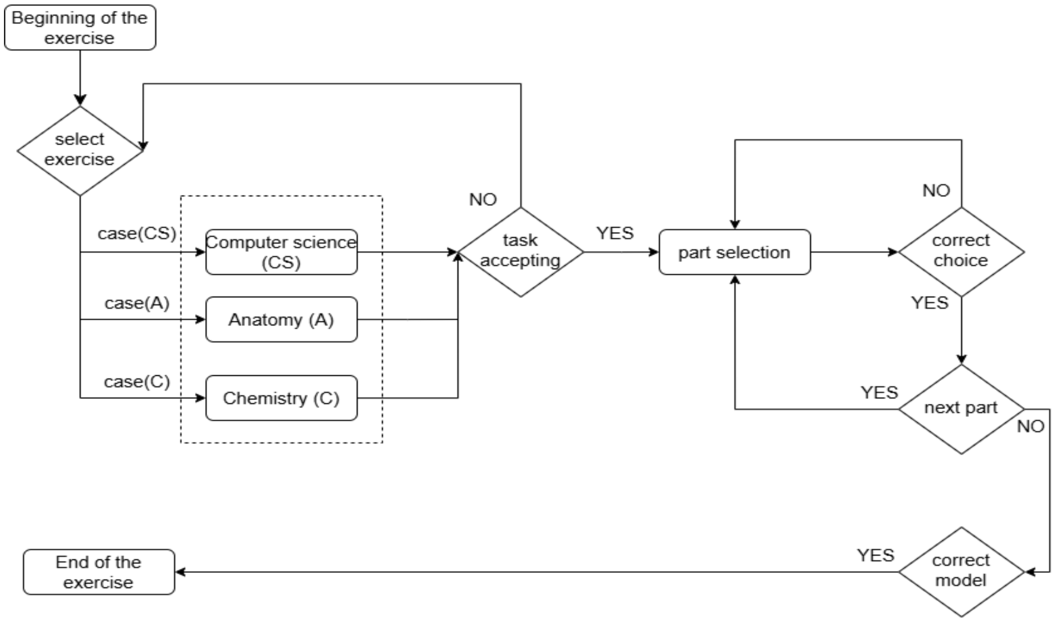


Fig. 9. UML Diagram

## 4. Results

In this research, we have implemented a virtual reality application to help disadvantaged students. From the point of view of the curriculum, it deals with three main areas of study, namely: chemistry, biology, and IT.

Considering that a VR application consumes important physical memory resources, the application is implemented in such a way that the users (students) can access it directly from the server. In order to make the connection, students will connect using a secure public IP. For increased security of the application, the administrator creates the credentials with which the users will connect. Upon request, users can access these credentials. Thus, they can connect privately.

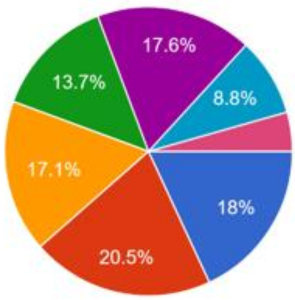


Fig. 10. Favorite feature of VR application

After logging in, students can access the application and start the game scenario. At the beginning of the scenario, they have the opportunity to access the game settings, namely the sensitivity of the mouse and the volume with which the sounds of the application are played. Setting these functions in advance, students can start the first scenario of the application, namely the biology one [29].

One of the questions that the users had to answer was related to the favorite functionalities of the application after it was tested beforehand. Fig. 10 represents the distribution of user responses, depending on the response options. The distribution of the answers is as follows: the first percentage, of 20.5%, corresponds to the option "Detailed graphics and amazing visual effects", followed by the one with 18% - "Intuitive interface". At close percentages, respectively 17.6% and 17.1%, are the options "The variety of VR experiences available" and "Engaging and immersive sound".

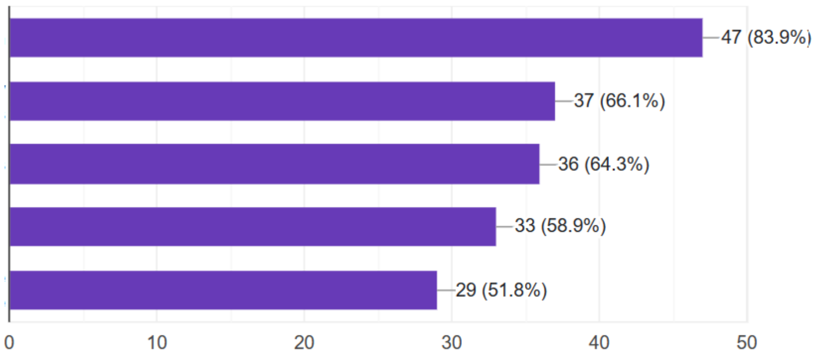

Fig. 11. What did you like about the VR experience with our app?

Fig. 11 illustrates how the users answered another question from the feedback form, related to what they liked most about the interaction with the developed application. The highest percentage, of 89.3%, is associated with the option "The feeling of total immersion", followed by "The possibility to explore new worlds", with 66.1%. 64.3% of users note "Interaction with virtual objects". On the last places, with percentages of 58.9% and 51.8%, are ranked "The feeling of relaxation and fun", respectively "Educational and informative experience". For our study we used multiple *comparison groups*, detailed as follows.

The first group is constituted by "VR Platform Users" such as students (blind responses on web forms) that interact with the immersive VR system, engaging with gamified educational content in virtual environments. This group is designed for learners from disadvantaged areas, special needs, or those without access to continuous study programs.

The second group is constituted by "Traditional/Non-Immersive Tool Users" such as students' colleagues of author use standard e-learning tools such as 2D simulations, video tutorials, interactive quizzes, and online lectures. It is designed for tools that lack immersion and interactivity provided by VR environments.

The *evaluation procedure* is detailed based on Participant Selection, Study Design and Data Collection. For Participant Selection, approximately 200 students colleagues of author (over 18 years old), divided evenly into experimental (VR) and control (traditional tools) groups. They include a diverse demographic mix: age, socio-economic status, and geographical location. The Study was conducted over a 3-month period where both groups learn the same material through respective methods. We implement periodic assessments and collect engagement and satisfaction data. The Data Collection was implemented using: Pre-test scores before exposure to learning methods; Post-test scores after completing assigned modules; Surveys and interviews to gather qualitative data on satisfaction and accessibility; Analytics on system usage (e.g., VR platform interactions vs. traditional tool logins). The Evaluation Metrics used to compare the effectiveness of both approaches are:

- Knowledge Retention: Measure pre-test and post-test scores for both groups to assess learning outcomes.
- Engagement: Track participation rates, time spent on tasks, and system interaction frequencies.
- Learning Efficiency: Assess the speed of grasping concepts and completing assigned tasks.
- User Satisfaction: Gather qualitative feedback through surveys or focus groups to evaluate enjoyment and perceived value.
- Error Reduction: Identify performance accuracy in tasks like experiments or simulations.
- Accessibility: Compare ease of use, especially for students with special needs.

Based on these metrics the evaluation results are presented in Table 1.

*Table 1*

**Evaluation results**

| Metric | VR Platform | Traditional Tools | Observation |
|---|---|---|---|
| Knowledge Retention | 87% | 68% | VR platform demonstrates higher retention due to immersive learning. |
| Engagement Rate | 92% | 59% | VR's interactivity keeps students more actively involved. |
| Learning Efficiency | 75% | 60% | Students grasp concepts faster in the VR environment with hands-on practice. |
| User Satisfaction | 4.7/5 | 3.8/5 | Feedback indicates higher enjoyment and perceived learning value in VR. |
| Error Reduction | 80% | 53% | VR allows safe experimentation, reducing mistakes in practical tasks. |
| Accessibility | 4.6/5 | 3.9/5 | VR is more inclusive, accommodating diverse learner needs effectively. |

Based on the evaluation results, the VR offers multiple benefits.

- Immersion: VR offers a fully immersive environment that enhances comprehension and application through interactive simulations, far surpassing static or limited engagement in traditional tools.
- Risk-Free Experimentation: Students can safely perform experiments without fear of physical hazards or material wastage — a benefit not provided by traditional methods.
- Inclusivity: The gamified VR system accommodates a wide variety of learners, including those with mobility impairments or special needs, improving accessibility.
- Enhanced Creativity: VR promotes constructivist learning, allowing students to construct knowledge actively, which fosters creativity and problem-solving skills.

We considered this subject important because it is one of the basics for admission to higher education in the science category, along with the second scenario, chemistry. Students discover, in an immersive and interactive way, the basics of the anatomy of the human body. With the help of the joysticks with which they test the application, the students can find out information about any part of the human body, both on the bony side and on the internal side. Next, the students will move on to the chemistry scenario, where they will have contact with the most basic concept to learn the discipline of chemistry, namely the periodic table of elements. In addition, they can do chemical experiments, but only after using protective equipment: gloves, gowns, and glasses. The application ends with a third scenario, namely the IT scenario. Students will learn software and hardware concepts, such as how to assemble a computer using its components.

## 6. Conclusions

This article presents the design and implementation of an accessible web interface for a virtual work lab. The objective of this initiative is to provide an inclusive educational platform for students from disadvantaged environments. The interface simulates the work environment for students in the fields of chemistry, biology, and IT, thereby facilitating access to various domain-specific skills. Moreover, the interconnection with other real medical systems can be done using standardized protocols such as Health Level 7 (HL7) [30].

The primary objective of this project is to remove barriers for students with special needs and facilitate distance learning through the utilization of web technologies and responsive design. This initiative is founded on the principle of equal opportunity in education by providing learning opportunities regardless of students' socioeconomic backgrounds.

The virtual laboratory is adaptable to individual student preferences, providing personalized feedback based on each student's progress. In addition, this virtual lab can be utilized to learn about geography and history [31]. This system has the potential to provide students from disadvantaged backgrounds with opportunities to acquire practical skills essential for a successful career. In general, virtual reality applications can be built around subjects that claim concrete concepts, such as those presented in the article, and are at the expense of abstract ones, such as philosophy, mathematics, and psychology.

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