

An Evaluation of Immersive Laboratory in Microbiology Teachings

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Abstract

Traditional teaching methods in microbiology often face limitations due to high costs associated with physical laboratories, leading to superficial understanding of microbiology concepts. This study aims to explore the effectiveness of a virtual microbiology laboratory in enhancing teaching and learning microbiology concepts, addressing the shortcomings of traditional methods. A virtual laboratory was developed utilizing VR technology, incorporating Cardboard Glasses and Bluetooth joystick controls. Blender was used for object modeling, and OpenSpace 3D served as the digital content creator. Twenty undergraduate biological sciences students participated, utilizing Cardboard-style devices and joystick controls. Three teaching methods—Exposition, Navigation, and Interaction with virtual objects—were employed. General usability heuristics were evaluated to identify didactic sequence flaws and assess comprehension. The study demonstrated the efficacy of VR technology in teaching detailed microbiology content, enhancing students' visual understanding and interpretation of concepts. The virtual laboratory facilitated immersive experiences, leading to improved comprehension among students. The findings underscore the advantages of employing a virtual microbiology laboratory to augment teaching and learning processes. VR technology offers immersive experiences that aid in effectively grasping complex microbiology concepts, thereby advancing microbiology education.

Keywords

Microbiological Studies, Virtual Laboratory, Virtual Reality, User Experience

1. Introduction

The rise of cutting-edge educational tools like Virtual Reality (VR) is prompting

a critical re-evaluation of traditional methods, especially in undergraduate laboratories. While Virtual Laboratories (V-Labs) have garnered initial research, a full exploration of their potential to transform undergraduate education through engaging and accessible learning experiences remains untapped (Gillet et al., 2005).

This transformation is fueled by the remarkable evolution of educational technology. Gone are the days of static e-learning platforms. Today, we have virtual labs, immersive VR worlds, and dynamic simulations, paving the way for a captivating new concept: interactive immersion. However, VR, a crucial component of this vision, was previously limited by cost and accessibility (Koh et al., 2010).

So, what makes VR unique? It lies in its ability to transport users into simulated environments and allow them to actively interact with them. This immersive quality fosters experiential learning, where engagement flourishes. Think about dissecting a virtual frog in biology, scaling a 3D mountain in geography, or conducting virtual experiments in chemistry, VR doesn't just show you these experiences, it lets you live them (Jensen & Konradson, 2017).

V-Labs, powered by VR technology, can revolutionize education by offering these immersive experiences (Checa & Bustillo, 2020). Imagine stepping into a virtual microscope to view intricate cell details, conducting delicate virtual experiments without safety hazards, or exploring distant galaxies in real-time. V-Labs unlock boundless possibilities for engagement, igniting curiosity and deepening scientific understanding.

Gone are the limitations of static diagrams and simulations. Today's V-Labs boast advanced features like intuitive hand and body control, realistic haptic feedback, and stunningly detailed virtual environments. These advancements blur the lines between reality and the virtual world, turning complex concepts into tangible experiences.

As V-Lab technology evolves, the learning potential grows exponentially. We can equip students with essential laboratory skills in a safe and accessible environment, foster collaborative learning across borders, and personalize learning pathways based on individual needs. The future of science education lies not in passive observation, but in active engagement with the wonders of science through immersive V-Labs (Allcoat & von Mühlennen, 2018).

With Virtual Reality Applications, it is possible to unlock a future in which scientific knowledge not only comes to life but jumps off the page and into the hands of every student. In this way, V-Labs will awaken a passion for science, nurture a generation of innovative minds, and transform how we learn and explore the world.

Thus, this work comes to the readers' attention by encouraging the use of V-Labs, as they can awaken a generation of creative thinkers, stimulate a passion for science, and revolutionize how we learn and discover the world.

The capacity to directly examine tiny organisms is critical to the learning process for undergraduate biology students in microbiology education (Mikropoulos

et al., 2003). However, many students need help connecting the complex realm of microscopic research and abstract theoretical notions. Consequently, educators must use cutting-edge teaching strategies to enhance learning results significantly (Garcia-Bonete et al., 2018).

To understand intricate biological processes that take place on various temporal and geographical dimensions, biology students significantly rely on interactive simulations, animations, and visualizations. Comprehending these procedures demands the ability to move between organizational levels quickly (Lee et al., 2009).

Students can acquire special visual abilities in microbiology using visualization programs in two-dimensional (2D) or three-dimensional (3D) forms. These applications facilitate a greater understanding of microbiological principles and allow targeted investigation of abstract topics, bridging the gap between students and microscopic occurrences (Shim et al., 2010).

The use of technology in biology has fundamentally changed how traditional teaching and learning are conducted, raising awareness among educators at all levels of education. Consequently, there is an abundance of opportunities for more investigation into the capabilities of Virtual Reality (VR) glasses, specifically concerning immersion and interactivity, regarding the creation of inventive educational applications (Garcia-Bonete et al., 2018).

Because VR-based learning gives students access to experiential learning that was previously only possible in well-equipped laboratory settings, it presents a revolutionary opportunity for educators. The virtual universe, which includes computer simulation programs that mimic real-world environments, and immersion, which generates a sensory experience of being physically and mentally present within the virtual space, are the four core elements that form the basis of VR-based education.

2. VR-Based Teaching

Students are becoming increasingly interested in virtual reality (VR) due to the extraordinary developments made in immersive technology, especially in terms of visualization and interaction. One of its most fascinating features is how students use gestures and speech to express themselves while using VR-Based Learning in the classroom (Gillet et al., 2005).

Because VR enables users to immerse themselves genuinely in virtual worlds and fosters an intense sensation of presence, research on learning feedback from students acquires significant relevance (Stauffer et al., 2018). While utilizing more realistic settings tends to heighten motivation levels, other aspects of VR technology, such as the screen refresh rate, might impact the amount of immersion experienced (Bailenson et al., 2008).

Additionally, educators' choice of learning model is influenced by the educational framework and the interaction made possible by virtual objects (Saunier et al., 2016). Using interactive and multimodal systems, such as virtual reality, might advance cognitive and perceptual psychology in education (Kolesnichenko

et al., 2020). Virtual reality (VR) technologies benefit educational research by providing a unique mix of high experimental validity and extensive control over critical factors (Xia et al., 2020).

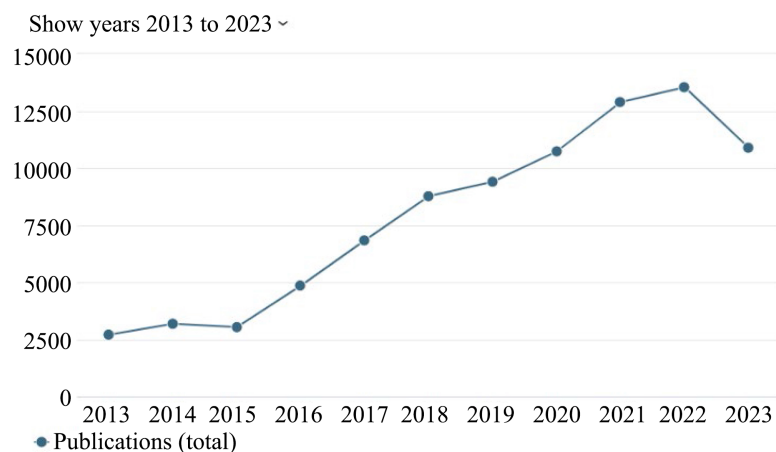
Teachers at all educational levels are now more conscious of the revolutionary effects of technology on microbiological teaching. In this sense, there are many opportunities to create creative educational applications while investigating the characteristics of VR glasses, especially those about immersion and interactivity.

Consequently, the real promise of virtual reality (VR) rests not just in improving teaching techniques but, more significantly, in opening possibilities for active learning experiences that are sometimes difficult to execute in conventional classrooms.

According to Jiang et al. (2007), the incorporation of educational technology, be it virtual or real, enhances the educational process and magnifies the inquisitive aspect of learning. In the end, when students interact with virtual environments, they implicitly understand basic ideas, which promotes cognitive processing and allows them to control their body's and mind's reactions when interacting with the virtual elements of their surroundings. This leads to effective learning outcomes.

Furthermore, traditional teaching methods are typically less adaptable and thrive in this situation due to the growing need for distance education in courses that call for a laboratory (Potkonjak et al., 2016). Therefore, given the significance of this bibliometric report as a catalyst for research into the best teaching and training methods utilizing virtual laboratories, mainly those developed in virtual reality, which foster greater immersion and engagement, Figure 1(a) presents a summary of publications from 2013 to 2023 on the use of virtual laboratories in science teaching.

A bibliometric analysis following the publications found between 2013-2023 shows a substantial increase in global interest in the subject. Furthermore, suppose we apply a search filter, considering only publications that impacted the area of Science Education. In that case, it is noted that this pattern of interest remains, as evidenced in Figure 1(b).



(a)

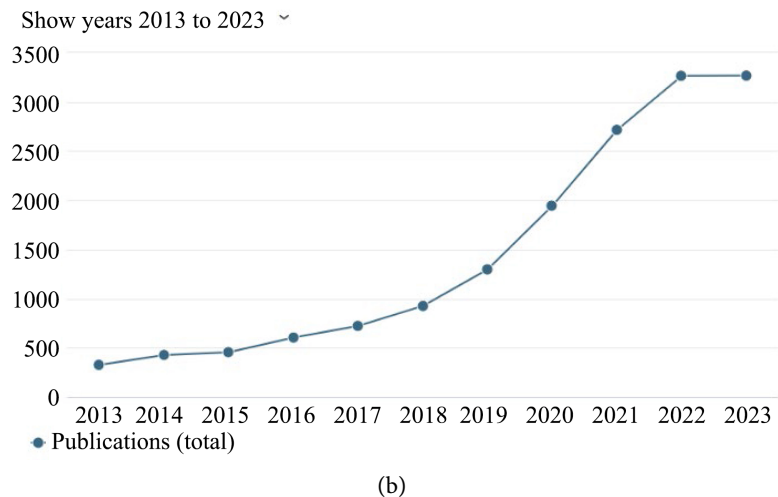


Figure 1. Related papers. (a) All publish paper in searching; (b) Science Education paper only.

3. Related Studies and Tools

The VR Lab is an increasingly common tool in genetics, biotech education, chemistry classes, and many other subjects. It is also used for professional skill assessment and training in several healthcare sectors. These virtual learning environments provide a more complete learning platform than a traditional lecture, which enhances student learning, motivation to study, and self-efficacy in final exams. Makransky et al. (2016) developed the VRLab simulator as a teaching tool to assist students in learning how to handle things in a physical laboratory. It has been demonstrated that increasing the immersion and engagement of the learning process, these simulations help students attain their learning objectives.

CellVerse is a different virtual reality environment designed for the classroom that gives students an impactful and captivating perspective of the biological world from within (Wang et al., 2019). Giving students the ability to choose and modify biological objects and images displayed on a screen helps them understand more about the studied subjects. With the 360° VR tour, students may familiarize themselves with and thoroughly immerse themselves in their surroundings (Johnston et al., 2018). This notion has proven engaging and motivating since it depicts microbiological life using colorful objects and pre-made animations. Another virtual reality game called InCell Game (Xia, Gao, & Zhang, 2020) is used to teach microbiology structures.

Based on our observations, creating a user-friendly environment that lets users explore virtual reality at their speed and offers direction to keep them from becoming lost or overwhelmed is essential for creating a good VR experience. Furthermore, most of the work highlights how important it is to have a guide for both the 360° tour and impromptu investigation to keep students' attention on the material being covered.

Some studies describe an instrument-based method of studying microbiology,

simulating bacteria, cells, and other microorganisms under a microscope with computer graphics. A virtual reality biology lab called OnLabs (Paxinou et al., 2020) aims to provide high realism regarding microscopy.

The user can choose from three distinct modes offered by OnLabs: instruction, evaluation, and experimentation. The user follows the instructions for the Instruction Mode's microscopy experiment. Under the Evaluation Mode, the user experiments and has their performance assessed simultaneously. Lastly, using the Experimental Mode, the user can experiment without guidance or evaluations.

Mao Miyamoto et al. (2019) created the Essential Laboratory Techniques Lab, a virtual resource for producing solutions and fundamental lab equipment. The purpose of this virtual lab is to teach students the specifics of each phase while also assisting them in understanding how the experiment works. Every lab experiment teaches the learner about a particular instrument and how to use it for biochemical research.

Interestingly, using a new virtual instrument becomes essential as the experience gets more complicated. Despite the keyboard and mouse being used for interaction, utilizing the application's capabilities feels like handling actual items.

4. Methodology

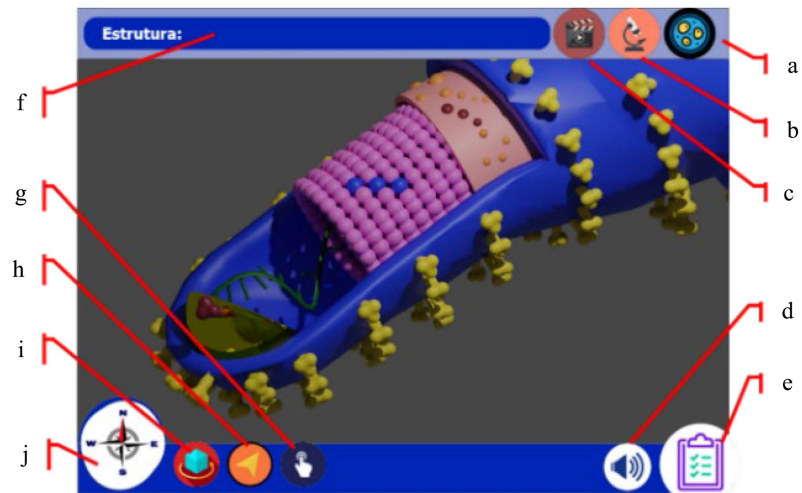
The literature study led to developing a descriptive research model to identify the characteristics of the virtual lab software intended for use in biology undergraduate courses. The methodological research model sought to carry out an evaluation.

Our project is centered around creating an immersive virtual reality teaching tool utilizing inexpensive head-mounted displays (HMDs) and controllers that resemble joysticks to facilitate interaction with the surroundings. We recognize that using virtual reality (VR) to educate in content detailing is essential for knowledge advancement and for students to appropriate learning items.

Twenty undergraduate biological science students participated in the experiment; twenty cardboard-like items served as the glasses; Bluetooth-style joystick controls were employed; and Blender object modeling was utilized to create the scene. Blender 3D was used to create the virtual models, while OpenSpace 3D was used to create the digital content.

The application was created in the Visual Computing Laboratory at UTFPR and was intended to run on two distinct operating systems: Android OS Mobile and Windows PC. The desktop version was created to assist teachers in guiding their classes during an exposition. A mobile version was also designed to allow students to immerse themselves in the generated virtual cosmos.

The tour and exploration of the surroundings are designed and led by the teacher, who also arranges the visuals. Finally, he or she activates the quiz feature so that the pupils may assess the material. Thus, **Figure 2** depicts the desktop platform application's interface hierarchy. It includes the regions denoted by the letters from a to j and described below.



Interface Layout

Legends:

- a) In Vivo viewer: Displays the natural environment scene from which the microorganism being study.
- b) In Vitro viewer: Displays the petri dish laboratory environment in which the microorganism can also be studied.
- c) Video player: Shows an instructional video.
- d) Sound: Enable ambient sound, when in vitro viewer is checked it displays a refrigerator motor noise, and when in vivo viewer is checked it displays a liquid flow noise.
- e) Quiz: Shows a quiz with multiple alternatives to check student achievement.
- f) Structure Name: Shows the name of displayed microorganism.
- g) Interaction Button: Provides the user to freely manipulate the displayed object, by touching some region of it and triggering an event, such as an animation.
- h) Navigation Button: Allows the user to navigate in the environment but keeping the presented object as the focal point of observation.
- i) Rotate Button: Enables the user to rotate the viewed object.
- j) Navigational Control: This allows the user to know which place to go to focus on the object of interest.

Figure 2. VR-Bio desktop interface.

In **Figure 3**, the mobile version is displayed. Since the ray tracing approach is utilized for linking, there are fewer interaction objects in this case. As a result, the user uses joystick control to interact with 3D objects. The icons for the three view types—*In Vivo*, *In Vitro*, and Video-player—are in the top right corner. The Quiz's initialization icon is at the bottom of the same side. Similarly, to ensure that the user does not misplace the object in the virtual world, an icon in the lower-left corner shows a compass.

VRBio runs on a local network, whereas the CardBorad visualization model is used on mobile devices. These devices are synced to access the same environment but generate distinct visualizations about the same object of study. The teacher's computer manages the desktop version of VRBio.

Multiple users may occupy the same area, but they may each customize it by adding things. Based on collision and impact theory, the area will function as a shell that permits geometrical and dynamic interaction between objects.

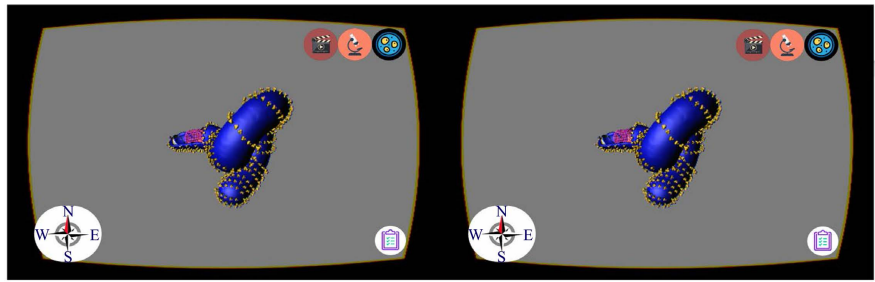


Figure 3. VRBio mobile/cardboard interface.

The assessment tool employed aimed to ascertain the virtual laboratory applications' usability characteristics (Ali et al., 2022; Radianti et al., 2020), categorizing them into three primary categories determined by the literature review: Features of the software's user interface (Software Operations); b) Characteristics of its use as instructional material (Educational Analysis); c) Characteristics connected to the assessment of learning outcomes (Learnings Outcomes).

The survey for students was laid out in **Table 1**, and answers were assessed using a Likert scale. Our set of questions allows for reflection on the usage of our application, considering the findings in related work and the proposed categories based on the teaching and learning process using virtual laboratories (Checa & Bustillo, 2020).

Table 1. Applications features.

Attribute	Question
Software Operations	a) Does not raise difficulties during the installation process? b) Does not raise difficulties during the Warm-up process? c) Holds to the standards customized by users (Menus, symbolic icons, etc.)? d) Users have the latitude to select and use any objects they want? e) Menus have easy-to-access location on the working environment?
Educational Analysis	It can cover the curriculum of the target group. There are difficulty levels for experiments. Experiment tools and sample experiments match with the learning and teaching attributes. The experiment tools show parallelism with the improvements in technology. The VR App immersion Topology
Learnings Outcomes	f) Makes studying program recommendations to students for effective use. g) Users can be evaluated based on their performance. h) What learning theories are applied to examine the use of VRBio App

This paper addresses the purpose of identifying the natural relationships with pertinent meanings of the educational context. The evidence and analysis supporting this claim respond to this purpose by directly interpreting and thor-

oroughly analyzing the methodology of developing academic activity through a VR-based laboratory miming *In-Vitro* studies.

This presents an in-depth examination of the objectives of evaluating virtual laboratory applications designed for undergraduate biology courses. The evaluation framework revolves around three main categories:

- 1) Features of the software's user interface (Software Operations)
- 2) Characteristics of its use as instructional material (Educational Analysis)
- 3) Characteristics linked to the assessment of learning outcomes (Learning Outcomes)

By elucidating these categories, this review aims to provide educators and researchers with insights into the critical aspects to be considered when implementing and evaluating virtual laboratory tools in biology teaching.

Integrating virtual laboratory applications into biology teaching has gained significant momentum recently. These applications offer immersive and interactive learning experiences, allowing students to explore complex biological concepts in a dynamic virtual environment.

However, to ensure the effectiveness and suitability of these tools for undergraduate biology courses, it is essential to carry out thorough evaluations that encompass various dimensions of usability and educational impact. In this review, we delve into the evaluation objectives that underpin the assessment of virtual lab applications, with a particular focus on user interface features, instructional characteristics, and effects on learning outcomes.

Software user interface features (software operations): The user interface of virtual lab applications plays a crucial role in shaping the overall user experience and usability. Evaluation in this category involves assessing aspects such as interface design, navigation efficiency, intuitiveness of controls, and accessibility features. A user-friendly interface increases student engagement and facilitates continuous interaction with the virtual environment, thus promoting a favorable learning experience.

As for the characteristics of its use as instructional material (Educational Analysis): Beyond mere technological functionality, virtual lab applications serve as instructional tools to facilitate learning and knowledge acquisition. Evaluation in this category involves examining how effectively the apps align with educational objectives, promote active learning, and support pedagogical approaches.

Key considerations include the clarity of instructions, the integration of multimedia resources, the provision of structured learning experiences, and the ability to accommodate diverse learning styles and preferences.

Moreover, finally, the characteristics linked to the assessment of learning outcomes (learning results): Ultimately, the success of virtual lab applications in biology teaching depends on their impact on student learning outcomes. Evaluation in this category involves assessing the extent to which applications contribute to acquiring knowledge, the development of skills, and conceptual understanding.

Researchers can employ various evaluation methods, including pre-and post-tests, performance assessments, and qualitative feedback analysis, to verify the effectiveness of virtual labs in achieving the desired learning outcomes.

The research subjects were 30 public school teachers who, after a short training course on the tool and its applications in the classroom, answered a questionnaire identifying the elements in **Table 1**.

5. Results

The information was gathered and put into the graphs shown in **Figure 4**, with each section about a different aspect of the educational tool's analysis, the software's functionality, and the intended learning objectives for teaching microbiology.

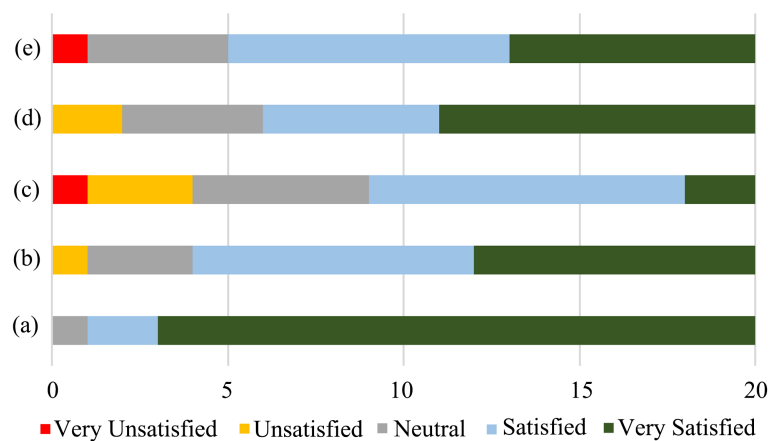


Figure 4. Software operation's analysis.

The usability and identification of menus and control buttons inside the interface in **Figure 2** still need significant work. Several constraints about the warm-up procedure are set inside the cardboard apparatus, including positioning and pain, which are provided as qualitative components.

As seen in **Figure 5**, other components—like additional visualization sites outside of a Petri dish—must be included in the 3D simulation to cover the target group's curriculum fully. In an interview with some users, it was mentioned that the surroundings needed to replicate the inoculation in a different live creature to track the microorganism's performance in real time.

We found no cognitive parallelism between the actual and virtual microorganisms for specific students. It could have to do with how light the cardboard viewer is or the colors the 3D model uses. The degree of difficulty of the experiment was shown to be crucial and closely connected to the kind of App immersion topology intended for the lesson.

An unexpected finding about the immersion topology of the experiment is shown in **Figure 6**. According to **Checa and Bustillo (2020)**, there are four categories for VR educational topology apps: exploratory, interactive, exploratory, and passive.

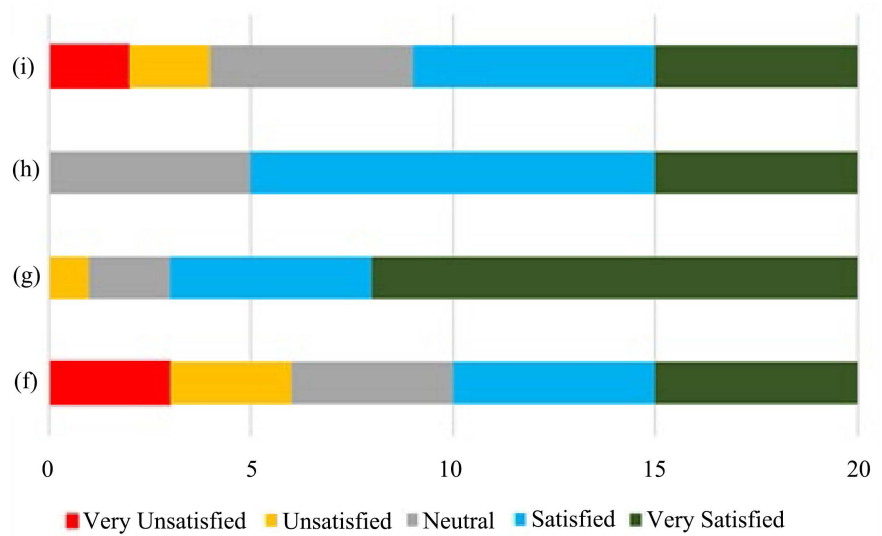


Figure 5. Education analysis.

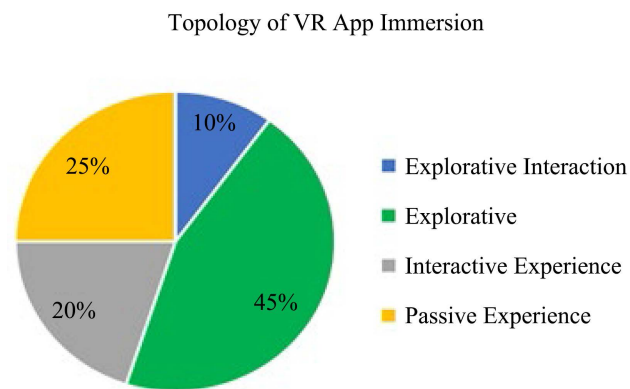


Figure 6. Topology of App immersion for education analysis.

Apps that let users freely explore and engage with a virtual world are known as explorative interactions. The exploratory experience is a more constrained approach that permits unrestricted virtual world exploration without requiring direct engagement. Users can engage with the surroundings through interactive activities but are not allowed to roam freely.

The last and least restrictive option is the passive experience, with minimal user exercise and interaction. A response from the pupils about a certain kind of interactive experience was required. But what happened was that many students understood that it is a free exploration environment.

With the artifact being used in virtual reality, Figure 7 seeks to determine the optimal teaching strategy. Behavioral learning theory sets up incentives or penalties for students to participate in the learning process.

So, this holds for VR programs incorporating an educational system that teaches students about the repercussions of their actions, such as when they obey or break the rules or when their actions result in pleasing (rewarding) or bothersome (punishing) outcomes.

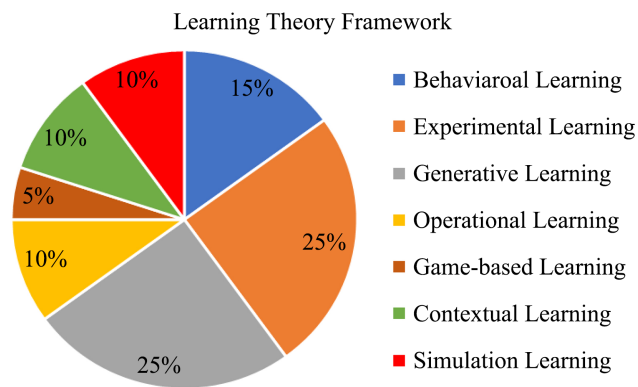


Figure 7. Learning theory analysis.

Experimental Learning is when students learn knowledge by practical application and apply analytical skills to reflect on it, and these reflections bring about improvements to the student's perception, emotions, or aptitudes. When students engage in cognitive processing during learning, such as sorting—that is, paying attention to pertinent information received—organizing—that is, mentally arranging information into a coherent structure—and integrating—that is, connecting verbal and pictorial representations and with previously learned pertinent information stored in long-term memory—they are said to be engaging in generative learning.

Operational learning is the process by which students construct or assemble an item. To learn computer assembly, they can interact with, choose, grip, move, point, and arrange things. When students learn through gamification—the incorporation of game design components and procedures, such as points, levels, and badges—and game dynamics, like rewards, competitiveness, and status—it is called game-based learning.

Contextual learning occurs when students concentrate on the context, which is the set of relevant circumstances for learning. Consequently, the learning material can guide students toward gaining insights by utilizing settings and strategies. Students are encouraged to think more deeply and complexly to expand their knowledge using virtual reality (VR). Teaching student in a virtual reality simulation in a secure setting is known as simulation learning.

The theories of generative learning and game-based learning—the ones most often checked in the experiment's assessment survey—have been determined by the students to be the most compelling theoretical approaches for applying the instrument.

6. Conclusion

This work corroborated break paradigms that require a high monetary cost when performing the application of immersive virtual reality in teaching microbiology in the classroom. Thus, we proposed immersive educational software using virtual reality for low-cost desktops and mobile devices that function as natural learning processes.

With the advent of VR-powered V-Labs, traditional microbiology education—frequently based on static graphics and physically constrained—faces a revolutionary possibility. V-Labs go beyond the simple transmission of knowledge by immersing students in interactive, real-world scientific encounters. Imagine working under a virtual microscope, carefully examining complex biological structures, or conducting delicate research in a risk-free setting. The days of passive observation are long gone since V-Labs actively involve students, promoting deep comprehension and kindling a passion for scientific inquiry.

Some biological science undergraduates who took the test applications demonstrated comprehension of the material and the development of skills necessary for microbiological research. It is stressed that this technology can help students learn more about the investigative scientific approach and make it easier to grasp these creatures' biological and biochemical activities.

The conclusion highlights the need for future studies with broader user bases and longer durations. It stresses the importance of collaboration between course administrators and instructors regarding V-Lab implementation, including instructor training and resource allocation, especially in microbiology education.

Furthermore, the potential of immersion learning to foster critical thinking, democratize scientific knowledge, and cultivate a generation of problem-solvers is emphasized. The conclusion calls for embracing V-Labs' revolutionary potential to create immersive learning environments and ultimately make scientific information readily accessible to all students.

Finally, the framework for evaluating V-Labs based on user interface, instructional design, and learning outcomes is presented. This framework empowers educators and researchers to make informed decisions regarding V-Lab selection, implementation, and optimization for improved biology education. Continued research and development are identified as crucial for solidifying V-Labs' position as essential components of modern biology curriculums.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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