

The Application of Virtual Reality and Augmented Reality in Biology Experiment Teaching

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Abstract. Since the evolution of VR and AR technology is developing at a phenomenal rate, they are being used more and more in education and adding new value to every level of biology lab education. VR offers a fully immersive 3D virtual environment, while AR places virtual information over the real world. Both help balance the drawbacks of traditional biology experiments such as the lack of specimens, expensive equipment, and the unavailability of viewing some processes. Students are now able to "enter" a cell and see organelles at work or view DNA replication in detail, which makes the lessons more effective. VR and AR are no silver bullet, however. Mass adoption remains with a number of hurdles, including technical maturity, development cost, and how it will be measured that people learn. They should not and cannot replace hands-on operation through genuine lab work. Instead, they are well-positioned to be an efficient addition to the traditional instruction, creating a hybrid "virtual-physical" learning environment based on the strength of each method. These types of software will play an even larger part in biology lab education in the future.

Keywords: VR; AR; Biology.

1. Introduction

VR technology has a whole virtual, immersive 3D environment. By way of specialized equipment, people are able to interact with this virtual environment. However, AR technology delivers computer-generated data, image, sound, or 3D model onto the real world. It places a digital layer on top of our world, thus expanding reality. VR and AR are being produced at light speed now into education. Both of them are also finding significant use in medical and health science education, particularly in biology lab education. These technologies make learning personalized and effective by enabling the learners to learn complex concepts graphically and interactively. Particularly the VR technology, it employs computer simulation and modelling to construct virtual 3D environments that resemble real. In its use through interactive tools, it replicates reality and allows individuals to engage in a world virtually created. AR, in contrast, combines digital information into the user's real world. In physiology, the interactivity and social aspect of such technology overcome the limitations of traditional pedagogy. Rather than replacing reality, it puts computer information atop what the user is currently perceiving, overlaying an extra level on their perception.

Through their computer-simulated 3D experiences, both technologies can transform standard biology lab teaching. In standard learning settings, students typically have the constraint of limited biological specimens, costly equipment, and inability to visualize complex processes through firsthand experiments alone. VR and AR can sidestep such limitations. For example, students can "enter" a cell to observe organelles functioning or vividly imagine the mechanism of DNA replication, making learning more efficient and engaging.

Though debate regarding the usage of VR and AR in biology laboratory teaching is increasingly being discussed with more case studies and initial studies now available, there is still no set or reliable model for their implementation in the classroom. Determinative points of issue like fitting contexts, functional usage, and impact assessment are still to be fully organized or thoroughly examined. In response, many instructors lack explicit theoretical and practical regulations to direct them in order to assist students. This paper is aimed at exploring the current use of VR and AR to teach biology labs, its effectiveness in use, and how it works towards the learning of knowledge by students.

Through this, it will seek to fill the existing gap in systematic research and establish a stronger theoretical basis for practice.

2. The Current Research Status of VR/AR Technology Application in Education

2.1. Application Scenarios of VR/AR in Related Educational Fields

VR and AR are already widely used in teaching areas such as medical anatomy, physiology, and dentistry [1]. For instance, in anatomy education, these tools assist students visualize complex structures in a 3D format, making the knowledge points easier to be understood. Some anatomical structures are difficult to examine because they are deep inside the body or surrounded by dense tissues. VR and AR can make the unclear structures to be visualized through features like layer-by-layer viewing and transparency effects. Other structures are too small or too abstract to see clearly with the naked eye, VR and AR can enlarge and visualize these, helping students connect form with function. Virtual dissection can also be conducted an unlimited number of times, without using real animal specimens. This not only supports animal welfare but also overcomes practical issues such as limited specimen supply and preservation challenges.

The program is being developed in different directions with experiments aimed at the sensory organs—vision, hearing, taste, and smell—to cope with prevalent learning disorders. For example, through a virtual eye test, students have a proper idea about the shape and functions of the eye. This is followed by a three-level model of learning: conceptual knowledge, skill acquisition, and competency attainment. This exposure helps the students develop a strong foundation of knowledge along with their hands-on lab practical skills [2].

In dentistry, AR can superimpose real-time data during procedures like dental implants, increasing accuracy and reducing patient suffering caused by operation errors. Meanwhile, VR can create a high-resolution 3D model simulating an actual patient's mouth. This allows dentists to practice procedures and hone their skills in a risk-free virtual setting. For complex procedures, doctors can repeat the procedure in VR to get to know the nerve and blood vessel structure of the patient and plan the optimum angle and pressure to use their instruments beforehand.

2.2. Break through Cognitive Barriers

Meta-analysis reveals that VR and AR technology and traditional pedagogical strategies have the same result when it comes to knowledge acquisition with barely some variations in test scores between learners. However, based on learners' subjective feedback, superiority of VR and AR technology over traditional pedagogical methods is more significant.

In biology education, VR and AR offers a simple practical advantage, particularly in some disadvantaged areas. Low-resource schools and rural schools may not have proper laboratory facilities due to financial restrictions or limited space, so students do not have much chance to perform hands-on experiments, particularly microscopic level.

In this context, VR and AR can reimagine experimental procedures in virtual environments and transform abstract concepts into tangible realities. This aids in evading the intellectual barriers with conventional pedagogy. Utilizing immersed imagery, interactive content, accessible design, and learning-oriented content in the manner students experience, VR and AR unlock potential in increasing the level of learning.

2.3. Students' Attitudes and Acceptance

Student reactions from settings such as online-based biology lab classes suggest that VR and AR are mostly viewed as an effective learning tool [3,4]. With the use of immersive simulated experiments, these technologies help to bridge gaps in traditional lab teaching and significantly enhance student participation and retention. Most students appreciate the expert content, smooth

operations, and clear visual presentation offered by VR and AR. Some others have suggested embedding the technology more within biology lab teaching to help improve learning.

In another survey on teen mental health, a VR device with complete latency of 29 milliseconds was considered low and can be used effectively on various types of groups regardless of gender, age, family background or living location. Total latency refers to the time passed between sensory feedback and user action; reduced latency allows greater immersion and safety. After three months of management, the test group supported with VR experienced improved scores of mental health that dipped to 50–55 points. The control group not receiving the management or the VR maintained scores in the range 56 to 65 points [3,5].

3. Future Applications of the VR/AR in Biology Experiment Teaching

3.1. Break through the Limitations of Reality

In virtual lab education and biology, VR technology is able to provide highly realistic videos substituting actual parts in a typical lab. Students are able to experience experiments firsthand in a 3D world while wearing a VR headset and rehearse the procedures with hands-on engagement [6]. Based on research, the process not only makes it easy to learn remotely but also eliminates practical barriers. In the case of hazardous chemical experiments like poisonous reagents, or tricky experiments with equipment limitations or limited space, VR has an obvious benefit—with the potential to have the students safely and efficiently conduct experiments.

3.2. Increase interactivity

AR technology is also creating new ways of building interactive instruments to instruct biology labs. For example, using wearable technology such as a VR vest, students can experience the virtual elements projected onto the physical world, like the rhythm and vibration of the heart [7]. This helps students better understand the relationship between structure and function in biology in a more experiential manner.

AR glasses are also in great demand in education. They allow students to visually view processes like DNA replication, blood flow, or photosynthesis firsthand. For instance, the student can watch how water is carried to stomata and see as such minute openings on the leaf surface open up and close. By depicting information in 3D, AR is superior to textbook two-dimensional images, allowing students to better comprehend abstract concepts and substantial justification of how students learn.

3.3. Enhance Learning Skills

During teaching in biology labs, VR and AR contribute significantly to enhancing the spatial knowledge and hands-on skills of students on the basis of their technical advantages. For instance, in neurobiology classes, VR is able to display 3D neural pathway scenarios, enabling students to see signal transmission as it happens from their first-person perspective. In learning cell mechanisms, AR can overlay 3D cell models onto existing images to show in a visual way how organelles interact with one another. Such methods complement the weaknesses of traditional teaching and enable students to learn complex topics better.

For the proper use of VR and AR to their fullest potential for skill acquisition, teachers must first identify students' spatial ability and practical experience, and adjust the virtual content accordingly. For less gifted students with weak spatial thinking skills, extra support in the shape of labelled 3D models and reinforced frameworks can be provided. For students with a sound practical experience, they can be pushed to try complex tasks such as designing their own experiments, and enhance their learning ability.

4. Challenges and Future Directions

VR and AR are being used more and more to many areas of teaching biology lab, allowing students to observe microscopic events such as cell division or replication of DNA on realistic 3D models. They can also allow students to try risky or costly experiments, allowing students to gain access to high-level material that it may otherwise be difficult to achieve. These technologies come a great deal of the way in bridging the gap between theory and understanding—although there is necessarily some restriction present.

While VR has a completely immersive 3D environment in which to observe microscopic occurrences like cell division and DNA replication, it can't compare to the physical experience that comes with actual teaching aids. In addition, VR isn't for everyone. Frequent use can cause motion sickness, whose symptoms include nausea, dizziness, perspiration, and general discomfort [8].

A US cohort study analyzed Veterans Health Administration data. Focusing on urban-rural differences in video telehealth (VTH) utilization for mental health care among American Indian/Alaska Native and other veterans (n=17,543,311) [9].

The population within the study was predominantly male (85.21%), with a mean age of 54.89 years. Researchers compared monthly rates from the preceding five months to nine months from the early pandemic period. Prior to the pandemic, non-American Indian/Alaska Native and urban veterans used VTH for treatment of mental illness at lower rates than rural and American Indian/Alaska Native veterans. During the early pandemic period, however, the pattern was reversed—with the urban and non-native populations well outpacing the others in VTH utilization.

Besides these differences in access, there are also constraints on the use of VR. Long-term use of VR headsets is found to cause skin irritation or allergic reactions in certain users, which is another aspect that cannot be disregarded [10].

5. Conclusion

Both VR and AR technologies offer convenient and innovative ways of instructing biology lab courses. Through simulative virtual circumstances and clear visual presentation, they render abstractions, such as cell structure and laboratory procedures, tangible, comprehensible substance. This enables students to understand challenging substance. Through VR technology, students are able to "enter" a microscopic cellular universe, observe organelles in action, and observe structure correlating with function in immediate time. Such concrete method of information delivery significantly diminishes the barrier to learning abstract information. Behaviors previously difficult to envision become interactive, allowing students to learn and gain valuable concepts at a more rapid pace.

Students show high acceptance of such technologies and are even motivated to study independently. Instructors in many cases report that students are more likely to use VR/AR to repeat experiments, focus on areas where they are weak, and create deeper understanding—substantially enhancing their independence in learning. In addition, VR and AR can also replicate high-risk or high-cost experimental arrangements beyond the bounds of traditional instruction. By placing more enhanced procedural information and revealing microscopic details not generally observed with human eyes, these tools advance lessons. They also offer distant or disadvantaged students equal high-quality learning content, evening out students on the same educational level. With precise interactive design, lessons become more interactive and dynamic, providing higher motivation and motivation in students. Policymakers will have to make cross-disciplinary coordination in the future. It can be implemented by setting up research teams with personnel from the fields of biology, education, computer science, and design to research VR/AR theory and increase the application of VR/AR theory in lab teaching.

Alternatively, continuous feedback from pedagogic practice must be gathered. This is done by tracking metrics like time students spend on web-based experiments, error rates, and quiz grades, and

how all these feed into learning key concepts. All these can be used to continually refine interactive material and design towards increasing levels of biology education.

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