Cell Tour: Learning About the Cellular Membrane Using Virtual Reality

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***Abstract*—Virtual reality (VR) technology has emerged as a promising tool in education, offering new possibilities for learning in immersive environments. This paper explores the application of VR in biology education, specifically focusing on teaching the functionality of the cell membrane. The traditional methods of textbook reading and microscopic observation lack interactivity and engagement, motivating the development of a VR-based learning approach designed as a game-like experience. The study compares the knowledge gain of participants who played the VR game with a control group who watched instructional videos. Surprisingly, the control group exhibited a higher knowledge gain compared to the VR group. Analysis suggests that the VR participants were more distracted by the immersive nature of the VR environment and focused less on the instructional content. Future research involving larger and more motivated participant groups, such as freshmen or high school students, may yield different results. Despite the observed limitations, this study highlights the importance of balancing immersive experiences with focused instructional content for better learning outcomes.**

***Index Terms*—Virtual Reality, Data Visualization, Student Engagement, Human-Computer Interaction**

I. Introduction

The advancement in personal computers and associated hardware has led to a revolution in graphical fidelity, resulting in increasingly complex and realistic simulations and virtual worlds. This has expanded the definition of what constitutes a learning environment beyond traditional classroom teaching and field trips. Virtual reality (VR) technology, with its ability to provide a sense of presence and immersion, offers new possibilities in education when implemented appropriately.

The use of technology in education is not a new concept, and its effectiveness has been studied for almost half a century. Early studies found that the use of computers to teach economic principles produced comparable learning outcomes to traditional didactic methods [1]. The release of the Oculus Rift made VR affordable for consumers and educational institutions, leading to expanded research and applied use in pedagogical settings [2].

One of the most significant contributions of VR to education is its ability to allow students to repeatedly practice complex and demanding tasks in a safe environment. It also facilitates experiential learning, allowing students to gain cognitive skills by exposing them to environments that are logistically problematic or impossible to visit in reality [3]. VR provides a direct, immersive experience of environments or situations that are difficult to replicate through traditional teaching methods. The key characteristics of VR involve immersiveness, which creates a sense of being present in the virtual space, and interactivity, which allows the user to manipulate the environment and test variables. These elements ultimately lead to a life-like perception of the virtual environment.

Our project aims to educate students about the functionality of the cell membrane using virtual reality. Traditional methods of teaching such a concept would have involved reading about it through a textbook, or by observing the cellular structures through a microscope. While the former approach can feel uninteresting to students just starting to learn biology, the latter does not provide much scope in the way of interaction. Our VR-based learning approach is structured using a game-like design where the students learn about the various molecules that interact with the cell membrane and their respective proteins by interacting with them. Televisions with information about the molecules are provided at every step, so the participants learn concepts as they navigate through the various stages. A scuba scooter is also provided as a locomotion provider which makes the game play fun and interesting.

II. Background

Previous studies have shown that students were highly engaged and motivated by VR experiences. They also demonstrate a high level of creativity and problem-solving skills in interacting with the virtual environments [4]. Johnson et al. studied how sixth graders engage in data collection in virtual reality to teach them the task in a science class [5]. They found that students gain confidence in real research, appreciate careful observation and that math concepts become more tangible and relevant. The experience also engaged typically less interested students.

ProjectScienceSpace examines how virtual reality can enhance learning of physics, chemistry and biology concepts [6]. Individual characteristics, such as gender and computer experience, can also impact the learning experience. VR features have a combinatorial effect on learning quality, and design trade-offs are necessary to optimize for interaction and learning.

Clarke and Dede show that immersive VR simulations outperform traditional instruction/board games [7]. Low-performing students excel in VR. Immersive learning enhances knowledge transfer, particularly in rich environments. VR improves preparation for future learning by simulating real-world problems. Merchant et al. conduct a survey of VR in education across 10 years in which they observed that desktop VR interventions produce a significant, positive effect on leaning outcomes and knowledge gain in K-12 higher education [8].

In a study conducted by Vishwanath et al., Google Cardboard and Google Expeditions were introduced into Indian classrooms to assess the impact on student engagement [9]. The researchers found that classes with VR were more engaging and interesting compared to classes without VR, which were perceived as superficial and dull. The study also found that the use of VR led to an increase in the number of questions asked in class and the length of discussions.

Alhalabi conducted a laboratory study where participants were randomly assigned to one of three VR systems or a non-VR control system to learn about four topics [10]. The topics were astronomy, transportation, networking, and inventors, and learning was assessed by quizzes. Results showed that any form of VR led to more positive learning outcomes compared to no VR.

Passig et al. investigated the impact of immersive VR, tangible blocks, desktop VR, and control conditions on young children's cognitive modifiability, which refers to their ability to adapt and adjust to complexity [11]. Children who used immersive VR exhibited increased cognitive modifiability, leading to enhanced analytic thinking, compared to those who used the other conditions.

Other studies note the limitations of using VR as an education tool. Makransky et al found that high-immersion VR resulted in greater presence but less learning than low-immersion VR and that narration did not affect learning [12]. VR may increase generative processing but also add extraneous cognitive load, limiting learning. Added immersion in VR could be a seductive detail that interferes with cognitive assimilation. Additionally, the study suggests in line with Van der Heijden, that students may view high-immersion VR simulations as hedonic, focusing on enjoying the environment rather than learning the material [13]. The article emphasizes the need for an overarching perspective that combines affective and cognitive aspects of multimedia learning to build instructional materials for immersive VR. The work has implications for the broader field of learning and instruction to expand cognitive theories of learning and instruction to make them more applicable to highly immersive environments.

III. Methodology

A. Participants

Participants were recruited from the social circles of the VR game creators. The group was diverse with graduate and undergraduate students from various disciplines. The study included 18 participants, 10 in the VR group and 8 in the traditional video/control group. The participants either did not have prior knowledge of biology concepts or learnt them too long ago to have remembered most of them.

B. Materials

The immersive environment was created using Unity software. Participants in the VR experience viewed the world through an Oculus Quest 2 HMD, providing three-dimensional stereoscopic views at a resolution of 1832 x 1920 pixels per eye at a refresh rate of 90 Hz (e.g., 90 frames per second, per eye) and 20 ms latency. The HMD includes an internal sensor that tracks the orientation of a user's head at a rate of 1 kHz. The external Oculus Quest 2 cameras were used to track participants' position in the virtual space, providing six degrees-of-freedom of head tracking, even though participants did not physically walk around. The virtual world was visually complex and computationally demanding, consisting of various cellular molecules depending on the participant's visual field, with animated objects throughout the experience. Participants stood throughout the virtual experience, hand-pressed the trigger and grip buttons of the standard Oculus controllers to interact with the virtual world elements including the televisions, a scuba scooter and cell molecules. The sounds were delivered using the Oculus Quest 2 earphones.

C. Game Design

A low-poly scuba scooter is used to enable locomotion in the VR environment. It provides a fun way of moving around the VR space. The user grabs hold of the scooter using the grip button and it stays in place without needing to keep holding it. Pointing the scooter in a particular direction moves the user along it. Televisions are provided along the learning area, which plays videos explaining the various molecules and their interaction with the respective proteins. The user can interact with them by pressing a button which enables the video. An example can be seen in Fig. 1

Molecules are grabbable objects that need to be placed inside the proteins. The user is expected to navigate using the scooter toward the molecules, grab them and place them in the proteins receptacles. The receptacles only accept the molecules if they are mapped correctly. The mapping is one-to-one, which means a molecule can only be placed in a

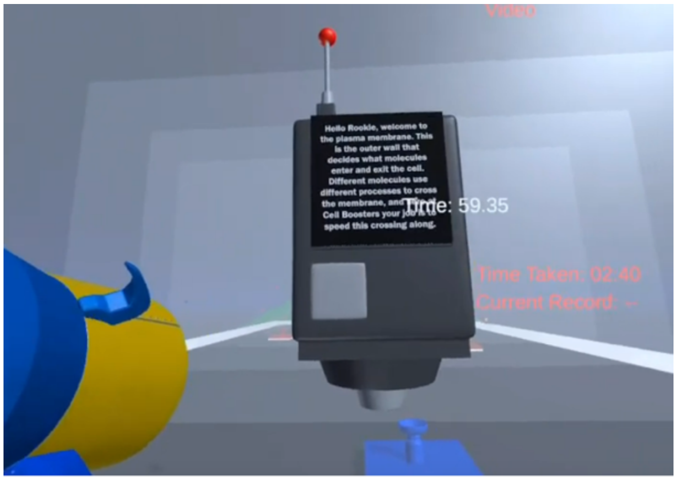

Fig. 1. View of the VR game tutorial area. Floating TV screen are located at various positions. Users can navigate to each TV to learn about the different molecules in the VR experience.

specific receptor and not other any other. Each molecule-receptor mapping is learnt in stages with walls separating each stage. The walls disappear when a learning stage is complete, which is marked by the end of a tutorial video on the TV, and practice molecules placed in the respective receptacle.

After completing all the tutorials the user takes an exam to test the concepts learnt during the previous session. There are 5 objectives which need to be complete for them to pass the examination. The objectives test the user to understand the mappings between the molecules and receptors and expect them to correctly map them with each other. The experience ends once the testing objectives are successfully completed.

The user screen space displays the progress of the game, the objectives and the time taken to complete the game. The user is also provided with an option to replay the game and beat their previous score, which is also displayed in the screen space.

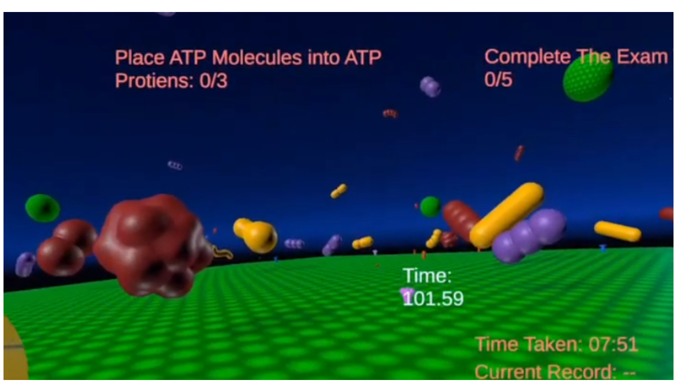

Fig. 2. Final testing area. Users would reach this area after completing the VR game's tutorial. Various of the developed molecules are shown.

D. Biological Components

The game focuses on the various molecules and their interaction with the cell membrane. Each molecule is expected to interact with a specific receptor, and the goal of the game is familiarize the player with the mappings between molecules and receptors. Examples can be seen in Fig. 2 Being an educational primer for the concept of cell diffusion, there are 4 types of cell diffusion represented by molecules that must each undergo a specific diffusion type. While the molecules are color coded to match their respective receptacle, they are each referred to by the name of the diffusion type they must go through (ATP Diffusion, Open Funnel Passive Diffusion, Gated Passive Diffusion, and Receptor Transduction). Players are prompted to create specific forms of diffusion during the testing portion of the game, which incentivizes memorization of the concepts within the learning videos portion to complete the final test with a low time. Otherwise, the player will still engage with the concepts of these 4 diffusion types (along with diffusion as a whole) via the physical act of passing molecules passing through the membrane while repeatedly reading the terminology to know which molecule is needed next. Visually, the nature of each diffusion type is reinforced by the receptacle that enacts said diffusion. For example, Open-Funnel Passive Diffusion is performed by a protein with a large open funnel (similar to a bowl), while Gated Passive Diffusion is performed by a protein shut tight by large blockers that only animate open when in proximity of their respective molecule. The Receptor Protien is more angular than the rest, evoking an almost technological affect since this protien transfers information similar to a phone line. Stylization was designed to be a compromise between accuracy and visual clarity of purpose. In reality, what the molecules look like isn't very comprehensible to the average viewer, hence why scientific diagrams stylize and simplify to increase understanding. We took a similar approach to these textbook diagrams with how we represented the biological components of the cell. Also represented are various nondescript blobs floating about the space, particularly within the testing area hovering above the cell. This was done to indicate that the body is teeming with other entities besides molecules waiting to be diffused (microorganisms, viruses, other cells, etc.). Without them participants might have gotten an overly simplified impression of the complex ecosystems of microbiology. Another positive is that the entities provided interesting visual landmarks within the testing area, along with obstacles to be maneuvered around while searching for the correct molecules to diffuse.

IV. Experimental Apparatus

The participant is randomly assigned to one of two variants of our study. In both studies, the user is asked to take a pre-survey that evaluates their current understanding of the cell wall. They are also asked to take a post-survey that tests their new understanding of the cell wall.

Condition 1 - Video-Based: This is the control group used to evaluate a conventional learning method. After taking the pre-survey, the user watches a set of short video lectures. The videos include concepts about the cellular components described in section III-D. The videos resemble a traditional classroom experience with diagrams and text, and a narrator explaining the various concepts. All of this is conducted outside of virtual reality. After the videos are completed, the user is asked to take the post-survey, which is then used to determine the knowledge gain through a traditional learning method.

Condition 2 - Virtual Reality-based: The user is asked to play the game and to follow the instructions within for reference on completing the assigned task. To start the game, the user must locate their position on the starting platform and watch the opening tutorial. They are then instructed to observe the colorful environment, take note of protein, module, cell wall, and obstacle placement around the level, and familiarize themselves with the scuba control on their left hand. The user should practice pressing the front trigger while pointing the controller for steering and become familiar with the HUD interface. The HUD displays objectives, displays the remaining modules needed to complete, displays the time, and moves with the user's head.

The user should navigate to the first module and start the brief introduction video to the corresponding protein. Each video gives an introduction to one out of five of the chosen proteins, as well as a condensed explanation of their function within the cell wall. The user completes the interactive task for that unit by placing the molecules into the protein receptacle that corresponds visually to that unit. Each protein receptacle and its molecule are color-coded for the user's convenience and will play an animation and sound to give feedback when done correctly. If the incorrect molecule is placed, the receptacle will reject it, play a sound, and return the incorrect molecule back to the user to use elsewhere.

The user then observes the transition to the final assessment by watching the barrier disappear. They then navigate to and commence the final assessment through interaction with a final module. In the final assessment, users are asked to deliver molecules to specific proteins in a randomized order using the same action as seen in the training beforehand. Unlike the training, the users are given only the name of the protein and are tasked with finding, navigating to, and placing the molecules in the correct receptacles. The user's goal is to complete the final assessment as quickly as possible.

After the user finishes the game, they are asked to take the post-survey. Additionally, the participant is asked to complete a questionnaire on topics such as engagement, motion sickness, ease of use, playability, and overall experience.

V. Results

The participants answered knowledge questionnaires each containing 11 questions on the cell membrane prior to and post watching the videos/playing the game. The difference between the scores was used to calculate the net knowledge gain. Surprisingly, the participants from the control group had the most knowledge gain of 3.75 points while the VR group gained 2.9 points on average. The time taken to play the game was measured and was found to be 29 minutes and 35 seconds on average. The creators' best time taken to play was 11 minutes and 44 seconds. The VR game participants gazed at the televisions for about 2 minutes 29 seconds on average. The total TV time was estimated to be 3 minutes and 25 seconds. The control group on the other hand gazed at the laptop screens almost the entire time the videos were playing.

The VR participants were also required to answer an experience questionnaire after the VR activity, with questions about the motion sickness during the game, playability, ease of use and so on. Each question was answered on a scale of 1-5, with 1 being the lowest value and 5 being the highest.

VI. Discussion

Our results indicate that participants learnt better using the traditional way of watching the videos than by playing the VR game. The VR participants were observed to be distracted while playing since they seemed more interested to fly around the VR space or interact with the molecules, than watch the learning modules on TV. This is evidenced by the reduced gaze time of videos in VR, while those in the control group studiously watched the videos. Our results align with the observations of Van der Heijden, who posits that VR users experience hedonistic pleasure from immersive VR, which hinders learning [13].

Our study has certain limitations, which include the small sample size of around 18 participants. Increasing it could reduce noise and provide a clearer picture of the actual knowledge gain in both scenarios. The selected group also consisted of acquaintances of the VR game creators, most of whom were in fields not related to biology and had no incentive to learn the concepts. Conducting the study with freshmen or high school students who aim to explore biology may provide different results.

VII. Conclusion

This study examined the use of VR in biology education, specifically teaching the cell membrane's functionality. A VR game-based approach was developed, but participants in the control group who watched videos demonstrated higher knowledge gains. This could be a structural issue, indicating that VR's immersive nature may have causes distractions that effects learning, or it may have resulted form shortcomings in our application. The speed at which the player moved was kept low to avoid motion sickness, but this might have created too long a gap between watching the learning modules and performing the test. A faster, maybe more traditional, movement system could possibly yield better results. The participants also may have lacked motivation to learn this topic, being college students with degree focuses not at all connected to biology. Younger participants (such as in high school) could be more receptive to this information due to naturally higher curiosity and less prior exposure to the topic of microbiology. Despite limitations, this study contributes to understanding VR's effectiveness in biology education, highlighting the need to balance immersion and instructional content for better learning outcomes.

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