Sea of Cells: Learn Biology Through Virtual Reality

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Abstract. Driven by the high fidelity and low cost of the latest head-mounted devices reaching the consumer market, Virtual Reality (VR) is a technology upon which rests increased expectations for improving education and training outcomes. The unique capacity of VR to produce experiences with high levels of immersion, presence, and interactivity, opens a series of prospects to improve the learning of declarative, procedural, and practical knowledge through a new modality of educational content. This paper explores some of the most promising opportunities of VR through the development and evaluation of Sea of Cells, an immersive VR interactive experience to enhance the learning of the prokaryotic cell. Methodologies to introduce the VR experience, both inside and outside classes, were also explored by analysing assessments from several Portuguese biology teachers. A test pilot made through video demonstration, shows a promising future for VR in education. Despite the physical limitations of the pilot study, due to Covid, after presenting the project to 7 10th grade Biology teachers, it was concluded that VR might be a relevant and innovative tool for educational settings.

Keywords: Virtual reality · Biology · Education · Cells study

1 Introduction

Education is a complex foundational pillar of a healthy society and, despite the attention and investment it drives, it is never considered complete, leading to a constant quest for improvements in the process of transmitting knowledge more easily, quickly and effectively.

The disruptive technologies brought upon by the digital era provide learners with a rich field of distractions, unfairly competing for the much-needed attention demanded by education systems that many students consider to only provide boring experiences. However, these same distraction technologies also create opportunities for more effective learning methodologies based on digital experiences with an engaging and meaningful power, far beyond current multimedia educational content.

Virtual Reality (VR) is perhaps the most prominent of such technologies due to its unique capacity to create experiences with unprecedented levels of immersion, presence, and interactivity. Combining the latest advances in VR technology offers a realistic

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opportunity to virtually travel to any part of the world, talk to anyone anywhere, and even see what other people see via video chat. Modern VR technologies are also capable of producing unprecedented immersion sensations upon which virtual worlds and scenes can be created to convey embodiment experiences that would be otherwise unreachable. VR proves more and more to be an asset to teach, train and prepare students and professionals in educational contexts such as university and professional scenarios, like the medical world [1, 2].

Traditional education has limitations regarding the representation of complex scientific concepts, even when resorting to multimedia content, like videos, 3D animations, and slideshows. In Biology education, VR has been shown to produce better learning outcomes for cellular structures and microscopic organisms when compared to video and textbook teaching [1]. VR is not a new technology, but its implementation in educational environments studies seems to be more related to performance and usability than the focus on the combination of immersion and teaching methodology to improve knowledge attainment, as highlighted by Jaziar Radianti et al. [3] the systematic review. From 2018, studies using VR as a tool to aid higher education have been increasing, showing a rapidly growing interest in its use in educational settings, certainly driven by the recent improvements in resolution and processing power combined with a sharp price reduction of the VR Head-Mounted Display (HMD) devices.

This work presents the development and evaluation of a pedagogic project aiming to take students of the 10th-grade Biology class on a journey to the cell scale. It seeks to enquire if VR educational experiences implementing proven learning methodologies promote better long-term knowledge retention. This journey takes place in a virtual scenario, where students learn about cells and what they look like from the inside, allowing them to touch, tear apart and see what lies inside the cell.

2 Related Work

A literature review was conducted through searches in scientific databases and an online search engine to identify projects and studies with a similar purpose to our work. Searching in databases like IEEE, PubMed, and ACM, we found a total of 63 studies related to our project, from which we selected 21 to be more relevant and a basis for this project and paper. This chapter highlights, from those 21, the most relevant studies, providing a brief review and critical commentary in relation to our work.

In [1], Onlabs presents a study where a class of 83 undergraduate students from the Department of Primary Education of Patras' university, who were enrolled in "Computers and Education" course, was divided into three cognitively similar groups. Each group knew nothing about the subject and took a test before the experience, after which they were then given learning material in 3 different modalities: watching a video, live presentation, or playing a VR experiment. The groups were retested immediately after being exposed to the content material. The study showed that students who took the VR experience increased 31% on their final score, while students using video and the traditional groups had only 20% and 15%, respectively. This shows the potential of VR technology to combine with traditional methods of teaching, probably because it provides more engaging and immersive experiences to students. In our work we implement a hands-on approach similar to the one adopted in this VR intervention, creating a link between what is expected from the student, what is taught, and what is experienced in practice.

Another study [2] showed that using Da Vinci Surgical Simulator 2019, where students observe an expert surgeon performing surgical procedures, may facilitate the learning of intermediate-level tasks such as basic camera targeting, intermediate energy dissection, energy switching, and advanced suture sponge. In this study, students were asked to identify every step of the expert surgeon before the experience, and after were asked to apply what they had just seen in this VR setting. Although they find that the experience may facilitate the learning of intermediate-level tasks to perform more basic tasks, using this VR context did not prove more or less efficient [2]. For the intermediate-level tasks, at least, this study creates a risk-free learning opportunity. By observing the expert first and then repeating each step with immediate feedback, the students can make mistakes with the notion that they will be corrected and guided by the experience in real-time.

Another study [4] used RobotiX Mentor VR Simulator [4], a training simulator that provides several exercises in the clinical procedures field, used university participants from beginners to advanced university students and practicing professionals. All three groups had to complete tasks controlling a robotic arm via a VR display. They had a checklist to verify if they were completing every task correctly. This study showed the advantages of a VR training curriculum allowing participants to track and monitor their progress, giving them feedback in what areas they made mistakes and what they can improve in the next training session, in a structured and professional manner through five exercises. It was concluded that Robotix Mentor VR Simulator was successful in establishing a benchmark for training in clinical procedures. Even though this study needs to be tested on a larger scale to validate its claims, a teaching method gives feedback to the student after each session, providing a better and direct understanding of the concepts wrongly utilized. This is a learning strategy "Sea of Cells" will also include.

Most of the publications described how VR was important due to its capability of exploring and visualizing concepts not available to the naked eye. LearnDNA [5] was one of the experiments that focused on developing prototypes to help students visualize DNA in a more immersive and realistic way. A total of 20 participants performed a user study in this iteration, out of which 16 were students from Eastfield College. These 16 students also participated in a specialized user study designed to evaluate pre-experiment and post-experiment knowledge. The first students took a written pre-test, then used the Virtual Environment (VE) system. After participating in the experiment, they filled out a survey and took a post-test. The other 4 participants were teachers and therefore did not take the surveys. The subjects that went under the VR experience also answered a survey to help prepare the next prototype. There was not an evaluation on how much they learned but on how much the experience worked efficiently. The students had to build a strand of DNA by placing the right part in the right place. There was a method to count how many times it took them to put the part in the right place for the first time. These results were stored in-game so that, after the experiment, the students could be evaluated. They were graded based on the survey answers they gave [5]. Relating to

"Sea of Cells", we find very important to create a space where the student can fail and try again.

Another work comparing the delivery of the same content through Interactive VR, Non-Interactive VR, or Video, aimed to determine if a more immersive experience would be a better approach to teaching. This study, making use of the "The Body VR, a Journey Inside the Cell", freely available on the Steam repository [6] concluded that not always the most realistic or immersive Virtual Environment (VE) provides the best teaching experience. In other words, the Non-Interactive VR environment proved to be the better of the three tested. Giving the user the 180º of vision to follow what was being described made possible for a better attentive experience, where the user felt more immersed and less distracted. Whereas in the Interactive VR version, the user was free to touch, use and explore more of the world shown, making it harder to sustain attention to the learning content. This study gave important insights to our work, showing how an experience design is more important than what the player can do, and that interaction is not always the best approach for learning purposes as well as the use of VR is more effective than traditional videogames [11].

The VR experience reported in [7] teaches how the cells work in the body by giving the user the point of view of a submarine type transport, allowing him to traverse blood vessels and watch as a narrator describes the function of each visible cell. Once again, it was demonstrated an increased demand for Serious Virtual Reality experiences, supporting the traditional education methods. This argument was also used by [9], where the user ventures inside a cell and touches various cell elements to understand better what each part represents and performs. This study, however, only concluded that the responses to their project were positive and made them look forward to creating even better VR experiences. These studies provide a base for creating a compelling and realistic experience. As [3] points out, realism does not mean that the rendering is as real as possible but might mean that the interaction of each part of the journey experienced in these papers is accurate. Having this type of representation can possibly prove more efficient in an educational setting, regarding the understanding of complex content. Following the conclusions from this study, we aim to create an accurate and artistic representation of the cell to ease the understanding of the organism's behavior.

Beyond the learning contexts, virtual reality has been a special technology used to teleport participants to the micro and the nano space. As examples, the work Noise Aquarium, by Victoria Vesna, recently presented in 2019 at Siggraph, shows vital micro creatures developed with specific 3D scanning techniques in VR environments [7]; and the work Sci-Fi Miners, a virtual reality journey to the nanocluster scale, presented by João Martinho Moura at the European Commission STARTS Science, Technology and Arts event, in 2020, where the author makes a journey to the nanoscale showing reconstructed 3D nano materials observed from advanced microscopy, and presenting simulations of future nanoclusters created at the International Iberian Nanotechnology Laboratory, in VR, on a theatre stage, to a broader audience [8]. Much like the representation of nanoclusters in Sci-Fi Miners and the microorganisms in Noise Aquarium, we focus on creating a VR environment where the student can observe Prokaryotic cells on a microscopic scale. While Sci-Fi Miners presents atoms and their interactions, we point to the cells studied in 10^{th} grade biology class and what constitutes them.

3 Biology 10th Grade Curriculum in Portugal

The main teaching methods in Portugal are very standard. The program is chosen preemptively, using a methodology to select a collection of learning material for the students to use. Once the program is developed and revised, teachers may choose their own pedagogic approach. However, the approach is practically the same in every school. PowerPoint presentations and an exercise book accompany the schoolbooks study to help students study at home. The biology program for the 10th grade is divided into 4 units:

a) The first unit approaches the processes of auto and heterotopia in beings of different degrees of complexity;
b) In the second unit, the subject's content puts in perspective the study of vascular systems as evolutive adaptations to the terrestrial field in beings with different levels of organization. The emphasis is placed on function, having the structural aspect referred to as an exemplifying functional solution;
c) The third unit focuses on transforming energy, mainly in utilizing the aerobic and anaerobic processes utilized by living beings. In animals and plants, the structures that allow gas exchange between the external and internal pathways are also studied;
d) On the fourth unit, aspects related to the maintenance of the organisms' internal environment conditions are addressed in the face of fluctuations in the external environment, by studying thermoregulation and osmoregulation in animals' and phytohormones in plants.

This work explores novel content delivery modalities and learning methodologies to the third unit. The traditional teaching methods usually have lab experiments, where the students use microscopes to observe cells and identify its components (Img.1). Some teachers also use the aid of videos where the cells are presented in 3D. Although there are very detailed videos, not every teacher uses them, and the students still cannot see what the cell does and represents.

With this experiment, the aim was to develop a compelling and exciting way to teach, demonstrate and display virtual reality as a tool for enhancing our school's learning methodologies. When learning a new subject or skill, it is important to have a positive attitude towards the taught content—establishing a connection with the presented materials to understand it better and motivate to seek more information about the subject. To this concern, Adrian von Muhlenen and Devon Allcoat depict a comparison case between video, textbook, and VR and how they relate to the student's motivation and want of understanding, concluding that virtual reality provides a better immersive experience in teaching and creating a more incentivizing method to keep the student's focus while learning [10].

Developing this motivational paradigm while learning and making school a more creative and amusing place is one of the main aspects, we are interested in investigating with "Sea of Cells".

4 "Sea of Cells"

In Sea of Cells, the goal is to immerse the students of the 10th grade of a Portuguese Biology class in a guided Virtual experience through an abandoned lab. Led by the imaginary inventor Zacharias Janssen [9], the students trace a series of steps to help the scientist understand where his last lab partner disappeared to, only to discover that students themselves would suffer the same fate. This experiment's primary goal is to take the student to a scale where the microscopic organisms are enormous, comparing to the player, something only achievable through Virtual Reality technology.

4.1 Experience Design

The main goal of this project was to create an immersive environment where the student could focus and stay focused on the taught subjects, and for this purpose, the biology teacher was met with to discuss how to create an entertaining but instructive experience, also to understand all the topics and materials used, and how they were explored in the classroom. The materials provided by the teacher were analysed and lead to the conclusion that the Prokaryotic Cell and the Eukaryotic Cell (Fig. 1) were interesting topics to explore in the experience because they are the basis of understanding how unicellular organism's work. These two cells stay relevant for the study of Biology in the 11th grade as well.

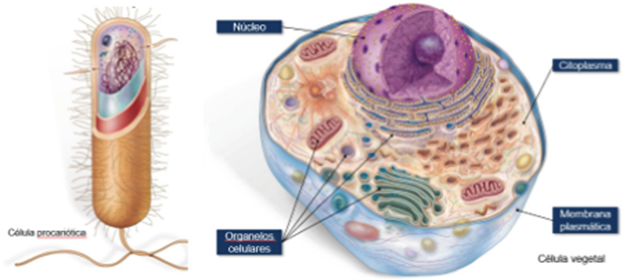

Fig. 1. Prokaryotic and eukaryotic cell. Source: 10th grade teacher material.

From this point, ways to present the cell without making it unrealistic while keeping all its components on display were studied. Starting with the laboratory, the goal was to mimic a biology lab with a satirical twist, a lab where the student could find jars with brains and a blackboard with comical value. The experience focuses on creating a link between the student and the microorganism, presenting them first and then allowing them to dive into the microscale to observe the cell. From interactions with a holographic cell where the student can learn about each part of the cell, the assembly of a microscope is then the bridge between the micro and our world. A space was developed where the student could "walk" freely and explore while still following a storyline, not to feel lost at any moment.

5 Development

5.1 Virtual Environment Considerations

Virtual Reality can be confusing to use the first time if not implemented correctly. When developing any kind of video game there is a need to prepare the player for what he is about to experience. Game design plays a big part in teaching the player how to interact with the world. If the goal is for the player to "jump" in the game, the game must be designed to let the user know what is expected of him. Allowing the player to learn via experimentation is better than telling them exactly what to do [11].

In virtual reality, several things must be considered, the height of the player, the position of objects in the environment, the strength of the lights, and other potentially nausea-inducing elements. There is a need to consider how the users will interact with the world and what can be done to make it easier for them. Virtual reality in an educational context should be clear and straightforward to use.

In the following development points, we point out what was taken into account regarding these game design concerns.

5.2 Virtual Laboratory

Considering the virtual environment design guidelines, the Sea of Cells experience starts outside of the laboratory, in a small room where the student must interact with the doors, providing a basic tutorial for all the VE interactions (Fig. 2). Virtual Reality mimics reality to an extent, so the same laws of physics apply when any force is applied to an object. Therefore, the student controls the speed and pace of the experiment.

Fig. 2. Lab entrance. Source: "Sea of Cells".

Upon entering the lab, the student is presented with the entirety of the space to show the user what could and would be the focus of the experience (Fig. 3). By taking advantage of this point of view, we direct the student to the first step into learning. The lab was created in the Game Engine Unity [12], making use of the Unity asset store, with a few exceptions, as the whiteboard, the prokaryotic cell, the microscope, the desk, the whiteboard pens and eraser, and most interactable items in the experience, that were developed in Autodesk Maya [13]. Each object in the scene has its own texture and reflections made with Unity and Substance Painter [14].

Fig. 3. Inside of the lab. Source: “Sea of Cells”.

5.3 Prokaryotic Cell

A first model was developed based on the materials destined to be taught in the 10th grade classes (Fig. 4). Making the connection with the materials, we want to reinforce the teaching methodologies.

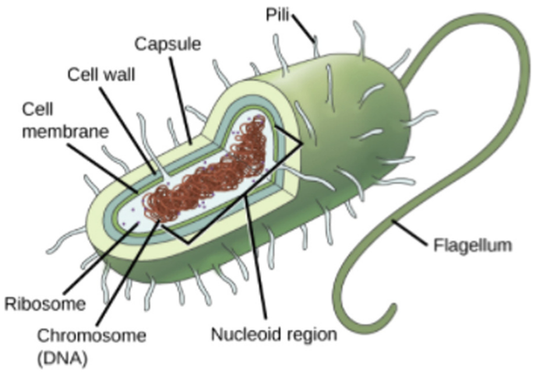

Fig. 4. Prokaryotic cell. Source: OpenStax [15].

A raw low poly mesh with multi-coloured separate sections, represent what each part of the cell contained following the slides provided by the teacher (Fig. 5). Although this corroborates what is explored in class, after consideration and several meetings with the biology teachers, it was determined that this was not optimal. As the goal was to create an immersive and fairly realistic experience, the model seemed out of place, and there was a need to achieve a more detailed model while still maintaining the relevance of each part of the cell. The second iteration of the cell was closer to the desired model, a transparent capsule that showcased its contents while retaining its structure. It was selected a more in-depth version for a more accurate interpretation of how each element behaved with one another (Fig. 5). Finally, it was necessary to create a shader that could provide a more realistic rendering of the cell. Created via Amplify Shader Editor [16], it was developed a texture capable of reflection and transparency, intending to obtain a softer jelly-like feel (Fig. 6) which turned out to be a good way to showcase every part of the cell while keeping a sense of realism.

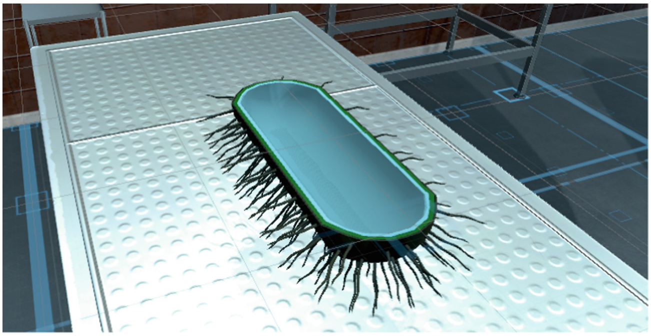

Fig. 5. First prokaryotic model. Source: "Sea of Cells".

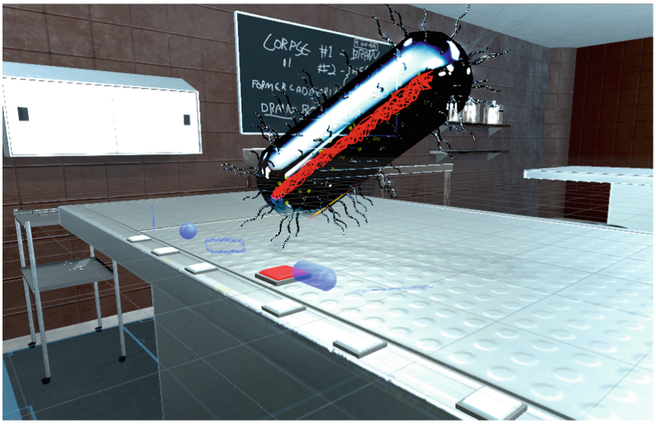

Fig. 6. Final model used in the lab. Source: "Sea of Cells".

5.4 First Interaction with the Cell

The first interaction with the cell must show and distinguish what each piece represents and its purpose. In conversations with the biology team, it was accessed that an interactive but straightforward holographic representation of the cell would be the most efficient form to communicate each element's particularities. To this extent, in one of the laboratory tables, there is a big enticing red button that brings forth the holographic display when pressed, along with several buttons laid out below the main one. Each of these buttons has a small visual display representative of a different part of the cell. When pressed, a voice-over would be heard, relating to a question and a text display in a data pad for the students wanting to read along with the voice-over (Fig. 7).

One of the main goals is to present students to each element before interacting with the cell in the final stage of the experiment.

5.5 Compound Microscope

An extensive and relevant part of biology is the study of cells.

One of the few ways to observe cells in real life is using a compound microscope. Therefore, students from an early age interact with and learn about this instrument, and students in high school must know and identify each part of the microscope.

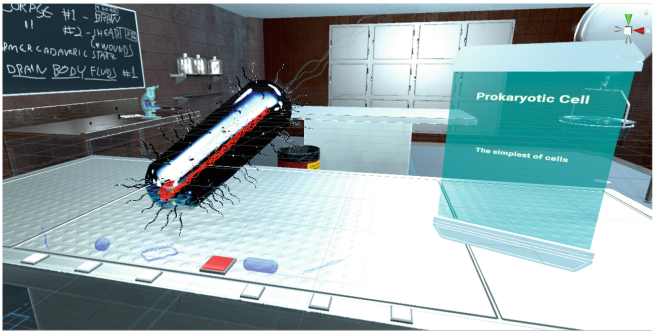

Fig. 7. Holographic representation, buttons and data pad. Source: "Sea of Cells".

Our meetings with the biology team concluded that it would be an interesting way to allow a hands-on learning experience to explore and manipulate inexpensively. Using Maya software [12] and following the design provided in the materials provided by our expert team, each piece of the microscope was modelled separately to allow then an assembly by the students while in the experience (Fig. 8).

A layout of the microscope is presented to the student. Guided by the instructions of Zacharias Janssen, the student must search for every part of the microscope scattered around the lab. With the help of an image and the witty remarks made by Janssen, the student learns where each part fits and how to pronounce its name correctly.

The purpose of this puzzle is to include a type of learning content much different from the cell, in this case, procedural knowledge about how to mount an artificial device. Moreover, the microscope challenge also explores different pedagogical methods, including game-based and behavioural learning, with students having to find every part of the microscope in order to advance to the next and final part of the experience in a fun learning environment. The expectation is that this way of learning enhances memorization of each piece's name and function.

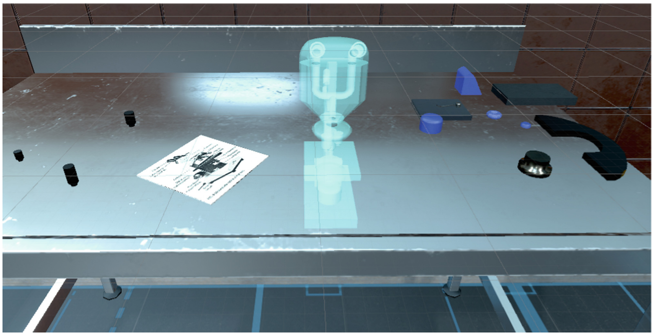

Fig. 8. Microscope layout and pieces. Source: "Sea of Cells".

5.6 Tele-Transportation to the Scale of the Cell

As the main goal of this project was to take the user to the micro-scale, a mechanic was developed to teleport the user to a new area where they can see the cell swimming around them (Fig. 9). A visual effect is triggered by a weary sound effect, giving the students a warning that something is happening around them. After a few seconds, the students are surrounded by prokaryotic cells traversing around them. At this point, the VR experience reaches its climax, having taken the student to the point of view of the cells, where they are enormous, and we are small (Fig. 10).

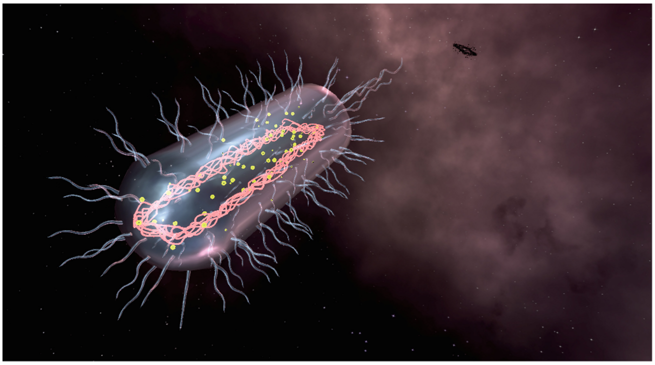

Fig. 9. Sea of cells climax. Source: "Sea of Cells".

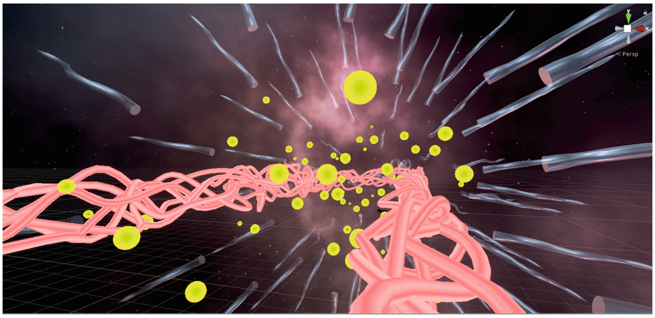

Fig. 10. Inside the cell. Source: “Sea of Cells”.

6 Pilot Study

Due to the global pandemic, we could not perform the desired study with the 10th grade class. Instead, we opted to create a demonstration to help assess what other biology teachers thought about the VR experience and what needs to be improved. A meeting was held with six teachers that had never seen the experience. The first author of the paper performed a demonstration of the entire experience, encouraging teachers to ask questions about the VE and how to move and work with it. After presenting the project and its purpose, the teachers were asked to answer a survey to classify the experience, how much they enjoyed it, suggest changes, and point any problems with the devised intervention.

It was interesting to note that none of the teachers had ever used a VR headset, but they felt they would like to use them in class to complement their school’s curriculum after the demo. It was also noticed a disconnection with the newer technologies. Most teachers said they do not use many forms of the new media in their classes.

7 Results

The study was conducted with seven 10th grade female biology teachers, with ages ranging from 37 to 60. When asked if the teachers had ever used Virtual Reality technology before, in class or elsewhere, only 1(14.3%) said yes, while the remaining 6 said they had never used it (85.7%) as shown in (Fig. 11).

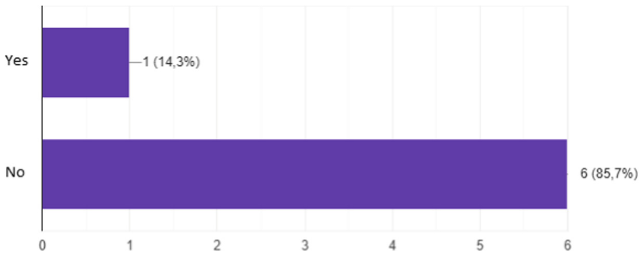

Fig. 11. Question about use of VR. Source: Survey conducted in pilot study.

On a scale of 1 to 5 (1 being very little and 5 being very much), when asked if VR shows a promising approach as a tool to help teachers explain complex topics in class, all seven teachers (100%) agreed that this technology as the potential to be very useful in an educational setting (Fig. 12).

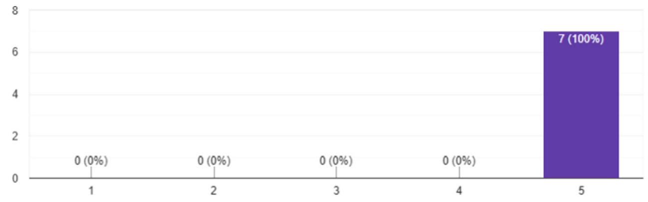

Fig. 12. Question about the relevance of VR in classes. Source: Survey conducted in the pilot study.

The survey also asked about the main mechanics in the VR experience. When asked about the final moment, the teleportation, six of the teachers (85.7%) said they could see it clearly happening, while one of the teachers found it hard to follow (14.3%) (Fig. 13).

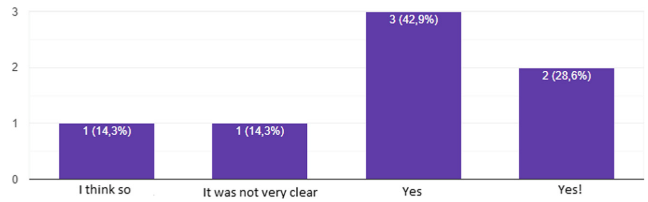

Fig. 13. Question about the teleportation. Source: Survey conducted in the pilot study.

There was a concern in asking about the accuracy of the representation of the cell in the experience. The teachers gave positive feedback about the rendering but alerted us to the importance of defining what prokaryotic cell we were presenting, as these can have many variations. Regarding the storyline and how the student is guided in the experience, when asked if it can be helpful to better prepare the student to understand complex topics: from 1 to 5 (1 being the worst and 5 being the best), one of the teachers (14.3%) answered 4, and the remaining 6 (85.7%) answered 5. (Fig. 14).

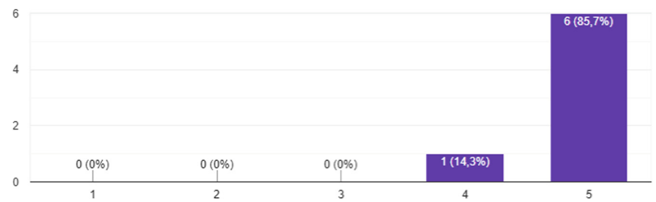

Fig. 14. Can VR prepare the student. Source: Survey conducted in pilot stud.

8 Discussion

Although the answers given by the biology teachers were mainly positive, there is still much work to be done regarding the presentation of the cell and how to better link this VR experience with the teaching methods used in class. The survey shows valuable feedback concerning the use of VR in an educational setting and gives the impression that the teachers would gladly implement this technology in their curriculum. This is a first pilot study that depicts the interest in the use but cannot ascertain how well this project would do in an actual classroom setting.

We found that only one teacher uses 3D animations or other animated technology to explain the dynamic of cells to their students. This corroborates A. Mesquita et.al [17] findings, that even though teachers know how to use some of the newer technologies as tools, most of them stay inside the curriculum and present its content more traditionally. Overall, the pilot study points to a favourable outcome for the application of this project in an educational environment.

9 Conclusions and Future Work

There is a growing interest in VR as a teaching tool, as shown by the systematic review conducted by Jaziar Radianti et al. [3]. This technology shows potential in creating worlds where students can explore subjects and train their procedural knowledge guided by a professor or teacher. Most studies presented here show an interesting approach to the application of VR in education, with positive feedback in its testing. Despite these studies and what appears to be a good outcome using Virtual Reality, it is still needed to create a link between what is being taught in classes and what is taught in the experience for better long-term knowledge retention.

This project was well accepted by the biology teachers that participated in the conducted survey, showing promising results to improve the effectiveness of the understanding of complex topics in biology education. The project was not tested as planned, due to the global pandemic and as such, this study could not ascertain if the VR experience was well implemented as a tool, but rather if the subject and how it was approached, was relevant in an educational setting. Taking the student to a different scale, while showing what cells are made of, shows a promising dive in creating a link between teaching methods and gamification, as also shown in [10] through the use of "The body VR" [6]. Following the answers given in the survey, all teachers agreed that VR might be a relevant tool to adopt in class to approach more demanding subjects.

We look forward to testing this project in 2021 with the students of the 10th grade class, hoping that this VR experience could be an advantage to shed light on the research questions we set to answer. Future work includes a broader coverage of the 10th grade biology curriculum and the assessment of different pedagogical methodologies efficiency in VR to improve long-term knowledge retention and create better learning experiences.

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