Virtual Classroom

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Abstract

The recent Covid-19 pandemic has highlighted the inadequacies of existing remote learning options, which have the potential to greatly enhance accessibility. Situations such as the aforementioned pandemic, inclement weather, personal health, disabilities, and other circumstances stand to benefit greatly from quality remote learning. However, traditional options like video calls and recordings have limited levels of interaction, immersion, and opportunities for "hands-on" learning that a physical classroom would provide. These aspects are especially important when teaching critical fields of study such as engineering, physics, and chemistry that have spatially complex concepts.

In this project, we explore the usage of virtual reality (VR from here on) as an interactive and immersive remote learning experience. As a proof of concept, we adapt a prerecorded video lesson on linear algebra for VR and record 32 UMD students' changes in quiz scores before and after each type of lesson as well as self-reported enjoyment and perceived level of learning. We observe a 20% greater increase in quiz scores for subjects that did the VR lesson, suggesting higher information retention in VR. Additionally, we observe that 47% of subjects enjoyed the VR lesson more, 25% enjoyed the traditional video lesson more, and 28% enjoyed both around the same. Our results support the capabilities of VR to create learning environments with greater immersion, enjoyment, and knowledge retention, highlighting its potential in remote learning settings.

Introduction

With the proliferation of technology in the 21st century, more and more aspects of our lives have been integrated and even replaced with remote, virtual versions. The recent Covid-19 pandemic has demonstrated the importance of having high-quality, immersive virtual experiences which can be safer, more accessible, and enhanced by technology. Even beyond the pandemic, many workplaces and schools are now embracing the option to have students or employees attend events remotely. However, studies have shown [insert reference] that remote attendees actually do not receive the same experience as those that attend physically. There is still something missing; if the teacher demonstrates something or asks students to look at an object for example, while those watching through video can still “see” the object, they will likely miss out on important spatial subtlety or perhaps part of the object that isn’t facing the camera.

In choosing a topic to teach through our VR experience, we considered several potential concepts from the fields of engineering, math, and computer science. We initially planned to teach a more directly hands-on task such as circuit building or testing a physics principle, however we decided to move towards a more simple topic. While the interactive nature of VR obviously lends itself to some of the aforementioned tasks, we felt that for our experiment the overwhelming advantage of having interaction via controllers would make our results unclear. Thus, we landed on teaching the vector dot product and some related principles, which are integral in applications such as physics and computer graphics (amongst many others). While this is an introductory topic in many STEM classes, for many of our participants with no prior experience in the field, concepts regarding the spatial position of objects in space can be very challenging. As such, we believe that this approach to teaching could make STEM much more approachable for many students who might be otherwise discouraged by the complicated diagrams and long equations often seen in these areas. Many students *learn by doing* instead of just watching.

By replicating existing highly-rated YouTube tutorials of this concept in VR, we hope to demonstrate that the benefits of VR could be extremely beneficial when applied to the top methods students already use for remote learning. In our personal experience throughout Covid, the vast majority of our lessons were taught in a very similar way; typically through Zoom using webcams to facilitate demonstrations or using a tablet to draw diagrams.

Related works

There have been several previous works that inform and inspire our approach to this problem. They show the potential of using virtual reality for various education-related applications, and provide promising quantifiable proof.

First, in their 2018 paper “Comparison of virtual reality and hands-on activities in science education via functional near infrared spectroscopy”, Lamb et al. utilized infrared spectroscopy metrics to quantify the benefits of using mixed reality. They used a specific type of spectroscopy known as functional near infrared spectroscopy (fNIRS) to measure hemodynamic response, which is the rapid delivery of blood to neural tissue. Increase in hemodynamic response indicates fluctuations in cognitive processing, which imply greater engagement. In their experiment, they presented users with a challenging topic; understanding DNA replication. They administered two lecture techniques, one in a standard lecture format and the other in virtual reality. The study found that the VR lesson had much greater hemodynamic response, even comparable with doing an actual physical activity. This shows the potential and advantage of VR over a remote lecture format.

In a second paper by Chen at al. in 2019 titled "Developing a hands-on activity using virtual reality to help students learn by doing," researchers conducted a similar study by comparing a standard lecture format with a VR enhanced experience. Here, however, they asked users to do an actual hands-on task; building a quadcopter. Then, they compared pre- and post-test results after users went through the experience, and found that VR had a higher increase in performance and hands-on ability (in the context of designing the copter) compared to the lecture format.

Together, these past works confirm for us the viability of using VR for education.

Research Questions and Hypothesis

We hypothesize that VR learning will result in higher perceived (subjective) enjoyability and learning as well as increased quiz performance.

Our research questions are:

RQ_a: How does perceived learning differ ratings between VR and video learning?

RQ_b: How does perceived enjoyability ratings differ between VR and video learning?

RQ_c: How does quiz performance differ between VR and video learning?

Thus our hypotheses are as follows:

H_{0a}: There is no difference between the impact that VR and video have on perceived learning ratings.

H_{1a}: Those who do VR have higher perceived learning ratings compared to the video lesson.

H_{0b}: There is no difference between the impact that VR and video have on perceived enjoyability ratings.

H_{1b}: Those who do VR have higher perceived enjoyability ratings compared to the video lesson.

H_{0c}: There is no difference between the quiz performance between VR and video lessons.

H_{1a}: Those who do VR have higher quiz performance compared to the video lesson.

Methodology

Lesson Content

We chose to teach the vector dot product from linear algebra, including the applications of computing angles between vectors and vector magnitude, as the topic of our lesson. We selected these topics as they are simple, visualizable concepts with a large amount of video lessons online. In order to fairly compare the effectiveness of our VR lesson to these video lessons, we included both a mathematical and a visual lesson. We sourced the mathematical lesson *Dot Product of Two Vectors* from The Organic Chemistry Tutor and the visual lesson *Cross Product and Dot Product: Visual Explanation* from Physics Videos by Eugene Khutoryansky, both on YouTube. The traditional YouTube video content was re-edited to remove irrelevant and redundant content, resulting in a condensed lesson covering only the dot product, vector magnitude, and vector angle computation using the cosine law.

3D Vector Model

The 3D vector model was created based on the visual video lesson. The 3D and interactive design of the vector model was intended to enhance student engagement with the material and provide a fun learning experience that would be more enjoyable as compared to learning in a physical classroom. Using the right controller of Meta Quest 3, users can manipulate the 3D vectors by pointing, holding, and dragging them and 1) scale them by shooting a blue laser with the index trigger and 2) rotate them by shooting a red laser with the side hand trigger.

Virtual Classroom Design and Implementation

The virtual environment (VE) is designed and implemented from scratch using the Unity Game Engine and the XR Interaction Toolkit. This VR interface provides additional functionality to the video lessons by allowing users to interact with the 3D, multimodal virtual lesson content using Meta Quest 3 headset and controllers. The virtual classroom is modeled after a normal classroom setting, with a blackboard, student desk/chair, teacher desk/chair, cabinet, and sufficient lighting. By design, the VR classroom was not populated with other student desks to avoid distractions from the main lesson content. The VR lesson content is identical to that of the edited lesson video, and its visualization is slightly adapted to the virtual classroom set up - it consists of an interactable 3D vector model and a screen behind it that shows the script and mathematical equations. A default white ray is cast from the right controller and turns green upon hovering over the “next” button. During the virtual lesson, the student can choose to interact and play around with the 3D vector model for as long as they would like before proceeding to the next scene (i.e., hover cast ray over “next” button and pressing a button on the right controller). The 3D vector model, lesson text, and equations are animated using C# scripts and on the video lessons, and the numbers in the example calculations are live-updated on the student’s desk as the user/student moves around the vectors. The 3D vector model and interactive nature of the VR interface are designed to improve retention of learned concepts while providing a fun and enjoyable experience for the user. In addition to visual content, audio clips from the video lessons were incorporated to corresponding scenes - this not only controls for differences between the VR and video lessons, but also enhances user's engagement with the virtual classroom lesson content.

In order to directly compare between the video (physical) and virtual classrooms, content from the video lesson was adapted directly to the virtual classroom scene using the exact same audio explanations and example problems. We acknowledge that our design choices are limited by the video lesson contents we were able to find online. (*see Future Work section for more in-depth discussion*)

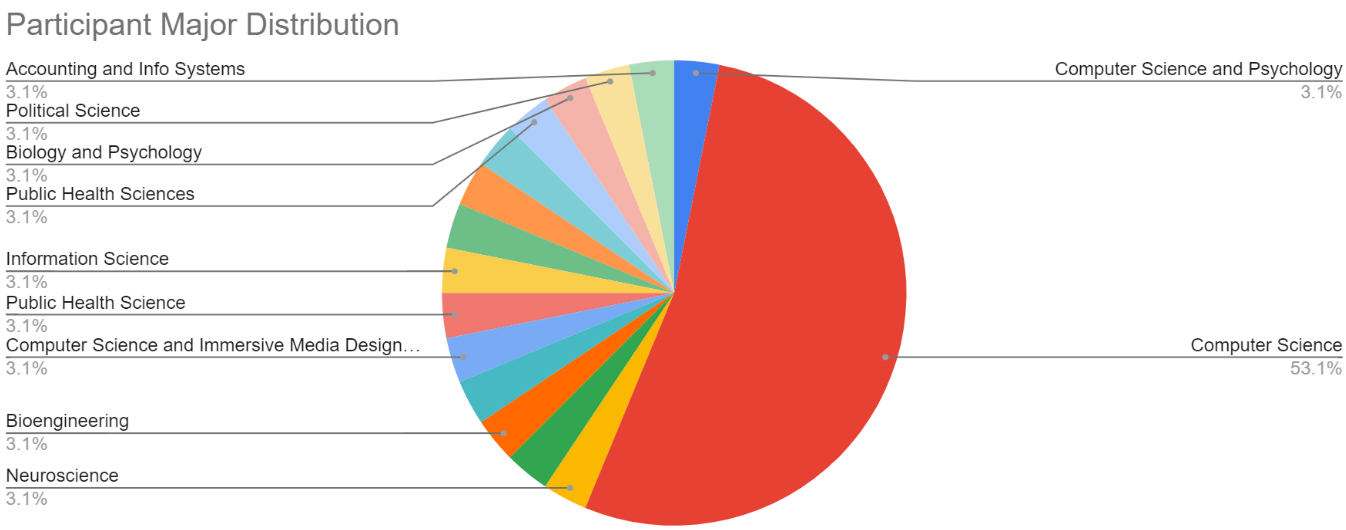
Experiment

The entire experiment consisted of seven stages: 1) pre-questionnaire, 2) pre-quiz, 3-4) virtual lesson and quiz, 5-6) video lesson and quiz, and 7) post-questionnaire. The order in which the VR lesson and video lesson was presented was randomized to mitigate ordering effects in the quiz results. The pre-questionnaire consisted of meta-level questions that aimed to gauge the subjects' familiarity with lesson content prior to learning through our virtual and video lessons. Participants were asked to answer questions such as "On a scale from 1-10, how much past experience do you have with using virtual reality (VR)?" and "On a scale from 1-10, how much familiarity do you have with the dot product?" The subjects were also given a quiz prior to learning in the VE or watching the video lessons. The pre-quiz tested subjects on dot product computation, magnitude and angle between vectors, and was designed to measure students' retainment of learning. Then, each subject was randomly assigned either to the "VR first" group or the "Video first" group, which determined the order in which the VE and PE were presented to them. After each lesson, subjects were given a quiz to test their knowledge again. The answers to the quizzes were not revealed until the end of all six stages of the experiment. Finally, subjects were given a post-questionnaire, in which they were asked to rate their level of enjoyment for the VR lesson and video lesson, respectively.

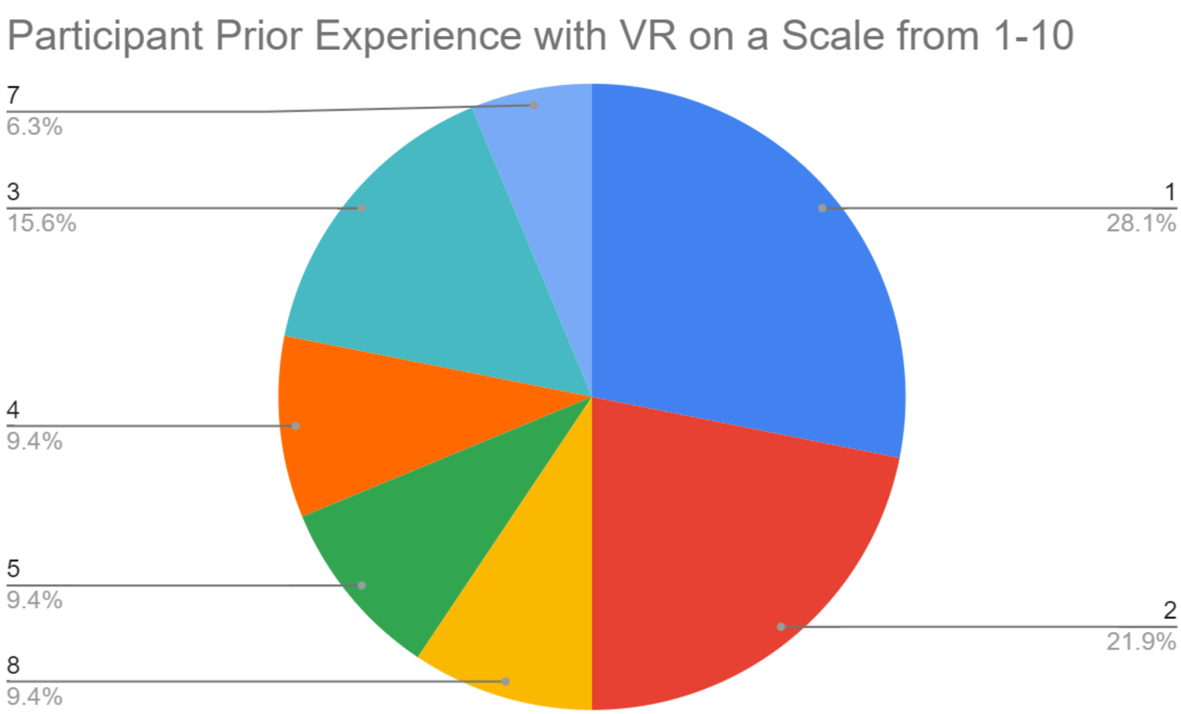
We recruited college students at the University of Maryland because this was the group of people who were the most accessible to do in-person experimentation. We sent messages in the club group chats that we were in as well as directly messaged people we know asking them if they wanted to be in their experiment. We met up with 32 UMD students, all of whom were undergraduate students except one who was a PhD student. We aimed to get a diverse group of students from different backgrounds and experiences in VR so that we would understand how VR and video lessons compare for people of all backgrounds. Thus, we recruited people of different majors, though most of them ended up being computer science majors as they were the most accessible. The experiments were conducted in various buildings on the UMD campus and were not constrained to any sort of physical environment.

Results

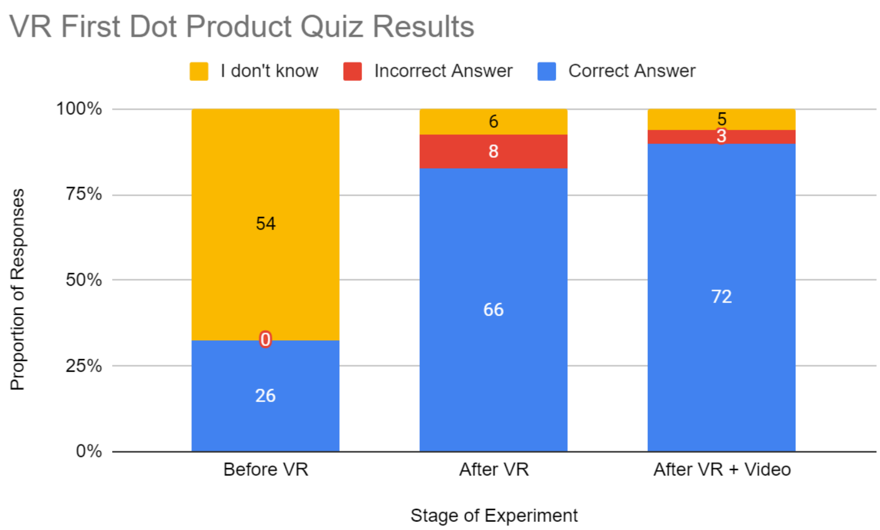
The below pie chart shows the major distribution of the participants:

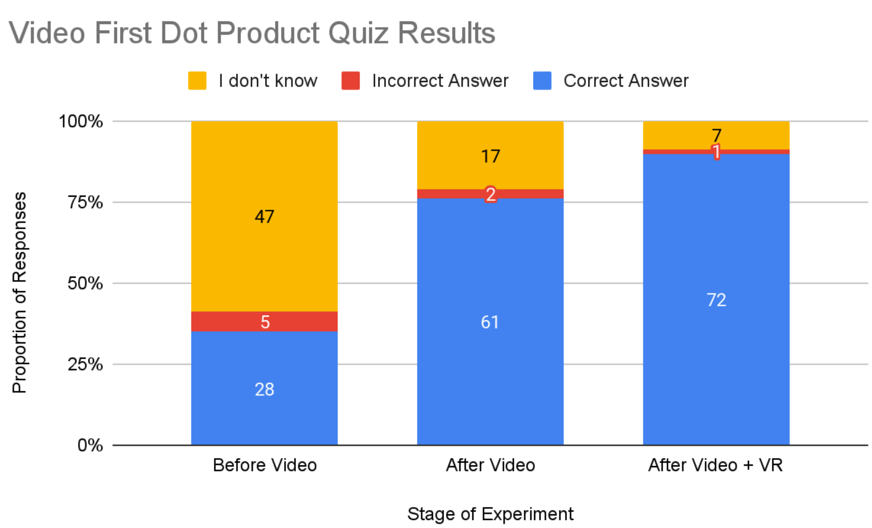


We also recorded participants' past experiences in VR in the pre-questionnaire where 1 means they have no experience and 10 means they have a lot of experience:

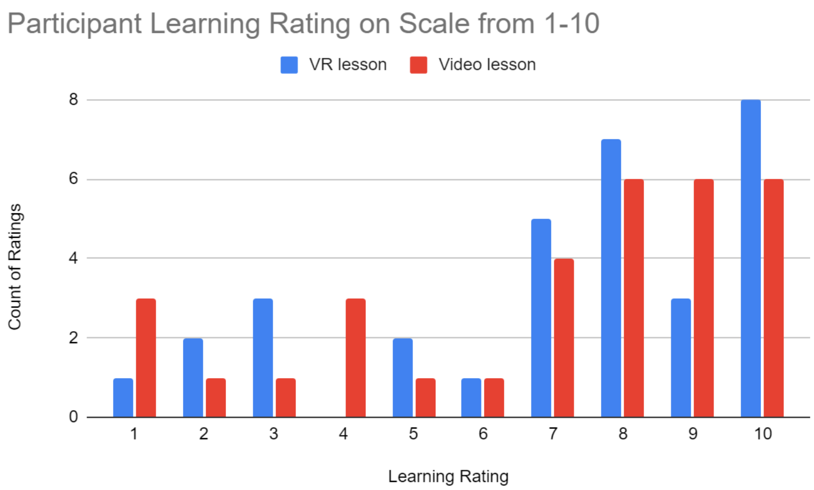


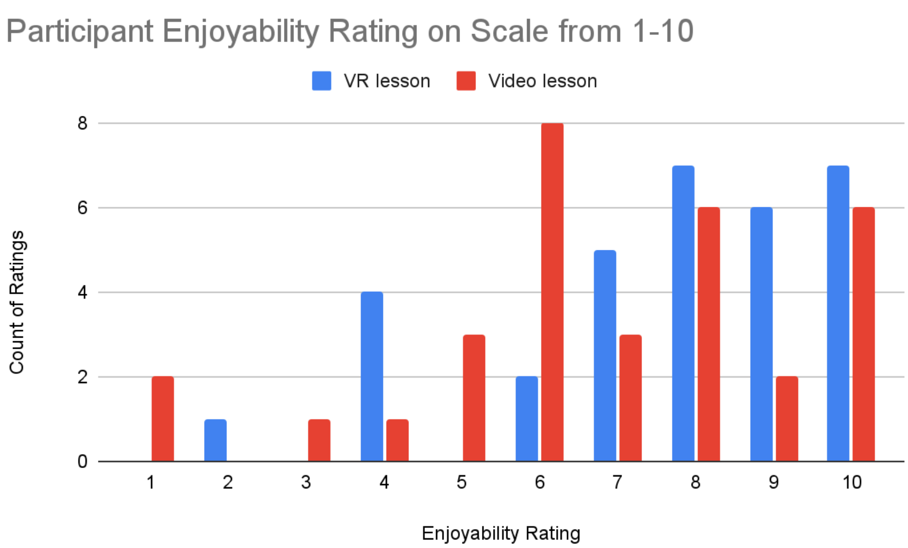
Comparing the correctness in quiz results before and after a participant has completed their first lesson, it is evident that users have a greater increase in performance if their first lesson is VR compared to if it is video. Participants before doing any lessons showed a 50% increase in quiz performance after doing the VR lesson compared to a 41% increase in quiz performance after doing the video lesson first. Moreover, looking at the quiz results after the participant has done their first lesson (stage 3), versus after they completed the second lesson (stage 5), it is evident that users have a greater increase in performance in this latter stage when the second lesson is VR compared to when it is video. Users who previously did the VR lesson had a 7% increase in correct answers after doing the video lesson, compared with users who previously did the video lesson had a 14% increase in correct answers after doing the VR lesson. Furthermore, both the video first and VR first groups had the same amount of correct answers in the post-experiment quiz. This is seen since out of all responses aggregated together, 90% of the answers were correct for both groups.





Looking at the post-questionnaire results, it is evident that the enjoyability and learning ratings are higher for VR compared to video. 47% preferred VR, versus 28% compared to traditional video. We asked all participants to rate their enjoyability and learning ratings of both VR and video on a scale from 1-10. From these results, 75% gave high enjoyability ratings (> 6) for the VR lesson whereas 53% gave high enjoyability ratings for the video lesson. Moreover, 72% gave high learning ratings for the VR lesson whereas 69% gave high learning ratings for the video lesson.





Looking at the written responses in the post-questionnaire, there are a mix of opinions on the VR lesson. While some said that it helped them focus because it was so immersive and fun to interact with the vectors, others said that it was overwhelming and too slow. The general complaint about the VR lesson was that it lacked the features of replaying, rewinding, skipping forward, and playing the lesson at 2x speed. All of these features are work that could be implemented into the VR lesson in the future. (*see Future Work section for more in-depth discussion*)

Addressing the first research question regarding the perceived learning rating difference between VR and video, running a t-test on the sample of data on learning rating for VR as well as learning ratings for video resulted in a p-value of 0.4372712102 ($p > 0.05$) so we fail to reject the null hypothesis that there is no difference between the perceived learning ratings. Moreover, doing the same on the enjoyability ratings resulted in a p-value of 0.1826004183 ($p > 0.05$) so we fail to reject the null hypothesis that there is no difference between the enjoyability ratings.

For the third research question regarding the differences in quiz performance between VR and video, we compared between two groups: 1) differences in correctly answered questions before and after participants went through the VR lesson and 2) differences in correctly answered questions before and after participants went through the video lesson. Doing a t-test for these two groups resulted in a p-value of 0.1155699972 ($p > 0.05$) so we fail to reject the null hypothesis that there is a difference between quiz performance in VR versus video.

Additionally, running paired t-tests on quiz scores before and after the VR lesson and video lesson resulted in p-values of 7.23951e-05 ($p < 0.05$) and 7.6954959e-06 ($p < 0.05$), respectively, which suggests that each of the VR and video lessons increased quiz performance - an indication of learning - in users.

Conclusion

Our statistical results showed that each of the VR and video lessons led to a statistically significant improvement in quiz scores in users/students. However, there was no statistical significance in quiz scores, enjoyability ratings, and perceived learning ratings when comparing the quiz results and participant ratings between the virtual and physical classrooms. We believe that this may be attributed to several factors, including 1) the relatively low level of difficulty in the dot product concept, which may have resulted in high quiz scores after both the VR and video lessons, and 2) the in-place nature of the VR classroom, in which users/students sat in a chair instead of moving around the classroom. Participants' written feedback suggested that they would be interested in improving their VR lesson experience through features to rewind, skip parts, or play the VR lesson at 2x speed. Thus, if VR lessons were to be implemented into schools in the future, it would be beneficial to add these features to the lesson. Following this, we note that our design of the virtual classroom was constrained by a need to model our virtual classroom closely after the selected video lessons to allow for direct comparison between VE and PE. We believe that lifting such constraints and adding more functionalities to the classroom will significantly improve users' learning experience and outcome.

Future Work

We hope to take this concept further in order to teach more complex topics in the future, such as circuit design from the field of computer engineering or the vector cross-product from mathematics. We wish to eventually apply VR within the educational system across all subjects of study. Such an application would also include functionality to allow users to play, pause, rewind, fast forward, or skip within the lesson just as one would with a video lesson. In this case study, we did not implement any resemblance of a virtual avatar or voice lines given by a teacher. Such implementations could also be included in the future to enhance the student's learning experience. For our implementation of the VR lesson, we chose to introduce and demonstrate each concept exactly as done in the video, maintaining order of appearance and equality of depiction. However, our attempt to closely mimic the video lesson may have hindered the design of the VR lesson since we did not utilize the full capabilities of a VR application, such as allowing for the user/student to walk around the classroom and interact with objects other than the 3D vector model. Arranging the VR lesson in a way that engages the user more may have been paramount to implementing a successful virtual learning experience. Specific improvements include displaying more comprehensive animations, gradually building up to mathematical formulas, and allowing users to engage in the third dimension. With the help of artificial intelligence, dialogue between the user and a teacher can even be personalized, further fine-tuning the learning experience to the user's needs. Moreover, this experiment can be conducted in other contexts, such as looking at participants of different ages, not just college students, or doing other lessons such as English or Science lessons. As education in VR becomes more capable, VR may be the future of education.

References

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