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CREATING VIRTUAL REALITY TEACHING MODULES FOR LOW-COST HEADSETS

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ABSTRACT
In the past few years, remote learning has been on a trend of steady growth and it is projected to remain on that course in the years to come. Additionally, the global COVID-19 pandemic forced a shift to remote learning which accelerated the existing trend to remote education. Unfortunately, learners find remote classes less engaging than traditional face-to-face classes. One technology that has shown great potential to improve students' engagement, both in face-to-face classes and remote classes, is Virtual Reality (VR). Nevertheless, while educators are no longer limited to expensive, high-tech, and high-fidelity VR hardware thanks to the introduction of low-cost, low fidelity headset, like the Google Cardboard, educators are still limited in getting relevant content and find it difficult to create their own VR teaching modules. With the objective to address these limitations, this work introduces a new process to create VR content that is easy, rapid, and affordable for educators to adopt and implement into their curriculum. The results indicate great potential for low-cost VR in remote learning as the sample of students in this study reported that they enjoyed the 'first-hand experience' of touring places that were inaccessible to them due to the pandemic. However, the findings also show a strong need to address usability issues such as blurriness and dizziness.

Keywords: low-cost VR, 360-panoramic, Google Cardboard

1. INTRODUCTION

Over the past two decades, remote learning has been steadily increasing due to technological advancements, the digitally native generation of students, and the societal shift towards convenience learning [1]. Jarvie-Eggart et al. [2] show that students enrolled in at least one online course increased from ≅10.8% to ≅ 31.6% of student enrolment in higher education between 2002-2019. This trend was expected to continue to grow at a steady pace [3]. However, the year 2020 saw a surge in online enrollment following the forced migration towards remote classes in attempts to curb the COVID-19 pandemic through social distancing [4]. Within the first two months of 2020, global education had 850 million students shift to remote learning [5]. Bates [6] predicts a subsequent steep growth rate before coming at a slower growth rate in 2025.

Unfortunately, remote learners find the content of online classes unexciting and less interactive than normal face-to-face classes [7], [8]. There is a need to engage the learner as this is correlated to a better learning experience and performance [9]. Several scholars have suggested immersive Virtual Reality (VR) as a potential solution to increase the engagement of learners with educational content [10]–[14]. Devon and Adrian [9] report improved learning experience and test score for immersive and interactive VR, in comparison to non-immersive video material of similar graphical and visual quality. They assert that learning VR technologies make abstract concepts materialize and more palatable for the student to understand [9].

Thanks to technological advantage in recent years, the cost of VR has been reduced drastically. One of the first commercial advanced headsets, the EyePhone, cost $9,000 in 1990 [15]. Instructors now have options of low-cost, low-fidelity VR hardware from gadgets including EVO [insta360.com] and Google Cardboard [arvr.google.com/cardboard], all for less than $20, to more advanced alternatives such as Oculus Rift [oculus.com/rift] for $299 and HTC Vive [vive.com] for $899. In addition, instructors have access to free pre-existing VR content from platforms including YouTube VR [vr.youtube.com], Google Expeditions [edu.google.com], or Sketchfab [sketchfab.com]. Instructors may also opt to create their own VR content from development platforms such as Unity3D [unity3d.com] or Unreal [unrealengine.com]. Unity3D, one of the most used game engines, allows for the writing of code, creating and importing animations. However, it presents a steep learning curve for beginners, especially non-programmers [16].

Even though the cost of hardware has gone down and there are platforms for content development, the creation of VR content still presents a steep learning curve and consumes a lot of time, which creates a barrier for educators. This is especially true for people who are new to programming or dealing with 3D objects [17]. While, some researchers are working on integrating Procedural Content Generation and Machine Learning methods to automatically create VR content [18], [19]; there is still a need for fast and low-cost content generation that educators can use now. For example, within a few minutes, Google Camera automatically creates panoramas from images, captured with a smartphone, surrounding the sphere of where the user is standing. These panoramic images can be viewed from the affordable Google Cardboard. Despite suffering frequent and plentiful misalignments, Google Camera demonstrates the potential for VR in education allowed by rapid development. Low-cost VR is already becoming mainstream. For example, in 2017 Google reach the milestone of shipping more than 10 million Google Cardboards since its inspection in 2014 [20]. It is important to recognize that low-cost VR headsets help democratizes the use of VR as it is affordable for lower-income users [21], like students in developing centuries.

While studies have introduced the use of low-cost VR for educational purposes, most of these studies do not show how to make the VR content. Moreover, VR content development is limited by existing environments or ground-level scenes that can be manually captured [22]. Nonetheless, the need for fast and low-cost development of VR modules for education that is engaging is still present. With the aim to help fill this gap, this work explores a combination of low-cost VR headsets and smartphones as an accessible, affordable gadget, and a combination of freely available software for an easy, rapid tool for creating low fidelity VR content that engages students.

2. LITERATURE REVIEW

2.1 Virtual Reality in Education

The use of Virtual Reality (VR) in education, or even in distance learning, is not a completely new suggestion [23]. Educators have used VR for various purposes including allowing students to tour sites that are inaccessible to visit, visualize 3D CAD models, and immerse themselves in simulated environments [24]. Studies have shown that VR increases the engagement, motivation, and critical thinking skills of students [25], [26]. Moreover, VR provides interactivity that allows students to learn through experience [27]. For example, a student can easily visualize a 3D object by rotating, expanding, or shifting it. Therefore, VR can help improve students' spatial skills and comprehension of structures [28]. In addition, VR allows for the simulation of processes making it attractive to STEM educators such as in Engineering or Chemistry. VR provides an immersive environment giving students a 'first-person' experience; hence, engaging most of the student's senses and increasing the learner's attention [29]. As a result, studies show that students who use VR perform better in their academics compared to students who interact with traditional class material (e.g., through desktop and keyboard) [30].

Thankfully, VR technologies are becoming accessible for instructors to use. Until recently, the use of VR in the classroom was not feasible due to the high cost of hardware [31]. In addition to the cost of advanced VR headsets decreasing steadily over the past years, low-cost VR headsets, such as Google Cardboard, have gained popularity as gadgets sturdy enough for classrooms [32]–[34]. However, even with exposure to affordable devices, there is still a lag in content creation that engages the learner. Similarly, instructors do not have a variety of content that fits into the context of their classrooms. In this work, a fast and low-cost method to create VR content for educational purposes is presented.

2.2 Low-cost VR in education

One of the most used low-cost VR headset devices in the market are the smartphone VR boxes, such as the Google Cardboard. They are an affordable alternative to VR head-mounted displays that can cost as little as 4 dollars per student [35]. These VR boxes are used together with a smartphone to immerse users in VR environments. In 2015 New York Times mailed millions of this type of headsets to its print subscribers for free [36], [37]. This is a tool that a lot of educators are leveraging. For example, Ahmed and Hossain [38] create an immersive education trip to a zoo using computer-generated models, and 360 videos with audio recordings of animals in their natural habitats. They report that students enjoyed the experience and found the Google Cardboard comfortable to use. However, their zoo tour was limited to ground-level views of a 360 camera so they suggest the use of drones to capture exciting aerial details. Unfortunately, drones are relatively expensive. For example, the DJI Mavic 2 Pro drone [dji.com/mavic-2], an industry-standard, costs US$ 1,349. Drones also present several regulatory issues as they are monitored strictly by both the public and government due to suspicion of privacy invasion [39]. Finally, drones may suffer camera shakiness during image capturing or bad stitching due to moving objects in the scene [40].

Yildirim et al. [41] study instructors using Google Cardboard and Google Expeditions application in various STEM classes. They were able to show that VR allows classes to carry out more experiments that would not be possible to implement physically. This includes going inside a volcano or viewing inside a nucleus particle. They report that even though VR increased student engagement and motivation, Google Expeditions primarily provided material to excite students which, often, were not relevant to the curriculum. Vishwanath et al. [21] used tours from the Google Expedition app and showed that students found them exciting while viewing on Google Cardboard. They benefited from Google's and other third parties' published tours, and believe that the continual publishing of material will improve learner's experience. However, they faced the challenge of finding relevant tours to the subject, resulting in a time-consuming search for tours. Nersesian et al. [42] ran comparisons between monitor-based and VR applications in STEM education. The group of students who interacted with the VR modules with the Google Cardboard performed significantly better. The authors argued that VR made understanding concepts easier through enhancing visualization of microscopic interactions of molecules. However, they also suggest further training for instructors was needed, due to the level of complexity instructors faced while using VR applications. Finally, Malinchi et al. [43] create a VR tour of an academic library to be used with the Google Cardboard in order to increase access to its resources. They achieve an immersive environment by creating a stereoscopic equirectangular panorama after setting up two identical cameras like two eyes, then capturing and stitching segmented images. They suggest the addition of controls on Google Cardboard to provide more interaction with the content and easier navigation through scenes.

The studies above show that while low-cost headsets are helping educators implement VR, there still a challenge for finding relevant tours for the subject in context resulting in a time-consuming search for tours, some couldn't find content or create aerial views, and others had difficulty dealing with complex platforms that provided VR content. Hence, a fast and low-cost process for VR content creation can help address these constraints. This study proposes creating aerial VR scenes using satellite imagery (e.g., Google Earth Studio) which is fast, inexpensive, and geographically extensive. It also proposes capturing images using a Hight-definition camera and stitching them into 360-panoramic images using available image stitching software for instructors to easily and rapidly create custom teaching modules that are relevant to their curriculum.

2.3 VR Content Creation for Education

Currently, researchers are working on diverse solutions to combat the issue of increasing educational VR content. One proposed solution is to automatically create VR educational environments using Procedural Content Generation (PCG) [19], [44]. PCG has traditionally been used in gaming to create new levels through heuristics or models trained with human generated content. This approach has great potential in education through the automatic generation of 3D immersive virtual environments that can be personalized to fit a context [44]. Nevertheless, this work is in its early stages and has not been tested in educational settings yet. Vishwanath et al. [21] carry out an experiment that involves educators downloading panoramas from the Google Expeditions app and creating tours that can be viewed using Google Cardboard and a smartphone. This approach is constrained to panoramas that are already created and to the pace of creators publishing panoramas. Alternatively, the instructor may opt to create custom teaching modules using the Google Camera application to automatically create panoramic images and audio recordings to guide the tour [45]. However, the Google Camera app can result in misaligned panoramas due to poorly stitched images. Advanced 360 cameras, such as Samsung Gear 360, could be used as a replacement to the Google Camera app [46]. Unfortunately, the price of this type of camera can range from a few hundred to thousands of dollars.

Instructors can also freely download published VR projects from Unity or developer kits with assets to create their own VR content. Unity 3D is a very popular game engine used to create high-fidelity virtual environments. For example, Lesniak et al. [47] find it to be the most reliable engine for rapidly creating realistic 3D environments, therefore they use it for 3D mesh reconstruction using algorithms and real-time rendering. Unity 3D provides developers a complete set of tools that can be used to create 3D models, scenes, or special effects for VR. For these reasons, several researchers have leverage Unity to create unique VR applications for training and educational purposes [48]–[51]. Unity provides direct access to VR systems and optimizes the rendering process of VR environments [47]. To bring about interactivity, developers need to employs programming languages such as C# or JavaScript. JavaScript is common among web developers, and C# is universal and compatible with various platforms such as Windows or macOS. These programming languages are used to create objects and their properties. Most developers search and copy code examples or 3D models from the internet to integrate them into their environments [52]. Despite these provisions, creating content in Unity 3D is still time-consuming and presents a steep learning curve since to create unique and interactive VR environment developers require some knowledge of computer programming, Unity tools, and interface, as well as familiarizing with 3D models and assets. This work sought an approach for content creation that can be implemented easily and rapidly without the need for programming knowledge.

3. METHOD

A procedure for creating VR modules is introduced in this work. Figure 1 shows a diagram of the proposed process in

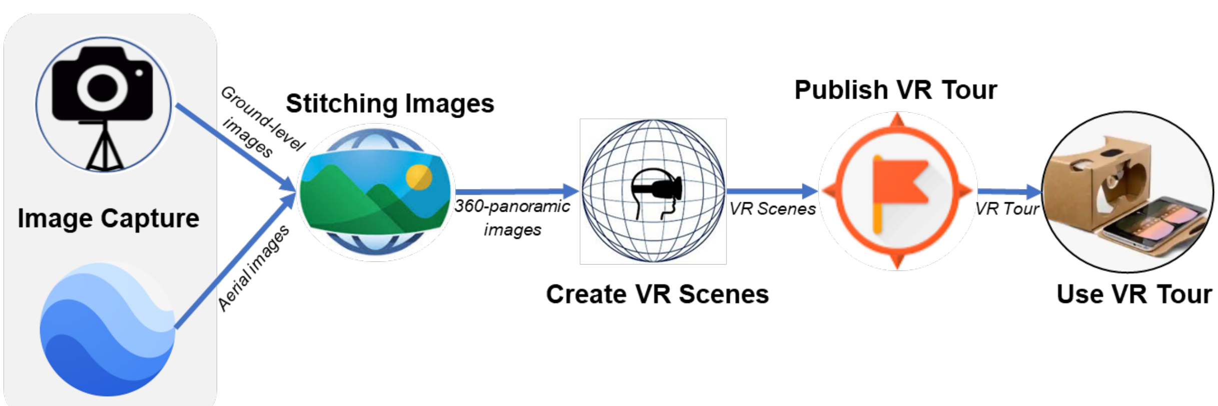


FIGURE 1. PROCESS DIAGRAM FOR CREATING VR CONTENT

whichground-level or aerial images can be captured and transformed into 360-panoramic images for use in a VR tour using a low-cost headset with a smartphone. A camera and a tripod are used to capture ground-level images which are then processed into a 360-panoramic image using stitching software. In this work, the PTGui stitching software [ptgui.com] is used to merge images into panoramic spheres. The software produces its output in Photoshop Document (psd), JPEG, or Tag Image File (tif). To capture the ground-level images, the camera is mounted on a tripod stand that could be rotated in every direction to capture the full surrounding sphere. The camera needs to be placed at the center of the scene and positioned from the viewer's perspective. At this stage, the tripod stand is not to be moved from its position and every object in view was supposed to stay stationary, otherwise, the panoramic image would not stitch well. In addition, the camera is rotated about the axis of the lens of the camera, as shown in Fig. 2, to avoid distorted stitching due to Parallax errors [53]. Images are captured by rotating 360 degrees laterally at different angles of tilt. To improve the quality of panoramas, higher resolution cameras are recommended (i.e., HD camera).

The proposed method also introduces a low-cost solution for creating aerial scenery for VR tours. This provides teachers an affordable way to teach details that would have needed drones to showcase. An aerial panorama serves as a complement to a ground-level panorama or other already published ground-level panoramas from platforms such as Google Street View. Specifically, in this work, the Google Earth Studio [earth.google.com/studio/] is used to capture aerial images which are also processed using stitching software to produce 360-panoramic images. Google Earth Studio is a 3D map based on superimposed satellite imagery. Google Earth Studio allows the user to photograph 3D views of anywhere on earth by levering in satellite images and Machine Learning. It is used to capture multiple images by placing a camera at desired location and altitude and rotating it about that point to avoid Parallax errors. Figure 3, shows an image of the user interface of Google Earth Studio and how it is used to capture multiples images to generate a 360-panoramic image. For example, the camera was rotated laterally in 30 degree increments and tilted longitudinally in 10 degree increments up 90 degrees to the horizon, as there are no significant pixel different on the images of just sky.

Stitching software often performs badly on plain images such as a clear blue sky; however, some software like PTGui, allows the user to manually insert control points to help the stitching process. The stitching software uses distinguishable markings found in images to automatically generate control points, an example is a corner of a building that appears in two overlapping adjacent frames. The increased overlap between the adjacent frames aids the software to identify more control points and process easier, but that comes at the expense of more computational resources required to process more images.

Interactivity and annotations can be inserted into the 360-panoramic images using a panorama editor to provide more details to the viewer, in this work Google Tour Creator was used. Images or text can be added to 'points of interest' for the viewer to pause and read the information. Transitions from one VR scene to the next can be created into a sequence with logical order. The resulting immersive VR tours can be then deployed on a VR publishing platform, like Google Expeditions which allows students to experience using Google Cardboard headset and their smartphones. The Cardboard provides several interaction modalities which include; head motion and location-based tracking which utilize smartphones inbuilt GPS and magnetic technology, and a capacitive touch button to select and click options displayed on the screen. The button can be used to navigate to other scenes and selecting a point of interest.

4. CASE STUDY

To test the capability of the proposed method to help create low-cost and immersive VR tours for educational purposes, it was implemented to create two VR tours that were used in geology and an engineering class. The first VR tour created for this study was incorporated into an Introductory Geology class to show students the Colorado and Little Colorado confluence.

FIGURE 2. CAMERA & TRIPOD SETUP

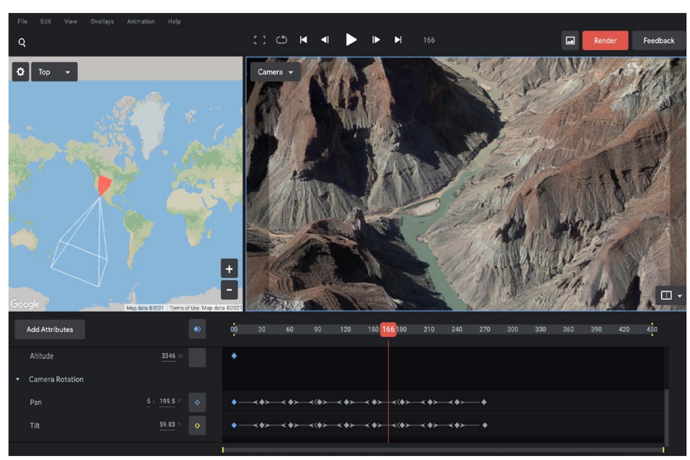


FIGURE 3. GOOGLE EARTH STUDIO USER-INTERFACE

FIGURE 4. AERIAL AND GROUND-LEVEL VIEWS OF THE COLORADO CONFLUENCE

The VR tour helped students study rock outcrops in the Grand Canyon by showing them aerial views as well as ground-level views of the confluence (see Fig. 4). This tour allowed students to immerse themselves in the Grand Canyon without the need to be physically present to study the geological formations and rocks. Moreover, the tour allowed them to see the Grand Canyon from an aerial perspective that would have been challenging to recreate in person. The aerial views were created using the satellite imagery provided by Google Earth Studio and stitching them together into 360-panoramic images. The ground-level views were taken from existing 360-panoramic images available in Google Street View. The students used the Google Cardboard and their smartphones to interact with the tour which contained four different scenes with multiple points of interest with detailed information about the geological formation shown. The tour was co-created with the geology faculty to ensure the scenes, points of interest, and tour as a whole aligned with the learning objectives of the class. A total of 46 students (57% females) interacted with the tour for approx. 10 minutes during. A video with some elements of the VR tour can be seen at https://youtu.be/l_ON7X5jKDU

The second VR tour created was incorporated into an Introductory Engineering class. This tour allowed first-year students to immerse themselves in the Mechanical Engineering Labs from the comfort of their homes, which helped them get familiarized with the labs and their equipment. The students used the Google Cardboard and their smartphones to interact with the tour which contained six different scenes with multiple points of interest with detailed information about the equipment of the labs as well as images of key components of the equipment (see Fig. 5). All the scenes were created from high-definition images captured with a normal camera and tripod (i.e., no 360-degree camera), and subsequently stitched together into 360-panoramic images. The tour was co-created with an engineering faculty to ensure the scenes, points of interest, and tour as a whole aligned with the learning objectives of the class. A total of 34 students (33% females) interacted with the tour for approx. 15 minutes. A video with some elements of the VR tour can be seen at https://youtu.be/pyeM-z2GgNM

After interacting with the VR tours, each student was asked to complete a short survey composed of two open-ended questions. The questions asked students to talk about (i) what they liked about the tour and (ii) what they disliked or could be improved about the tour.

FIGURE 5. SCENE FROM THE ENGINERING LAB VR TOUR

5. RESULTS AND DISCUSSION

The students' responses to the open-ended questions were analyzed using multiple text-mining techniques. From the geology VR tour, a total of 43 responses for the first question were obtained, and 41 for the second question. Similarly, for the engineering VR tour, only 30 responses were obtained for both questions. Table 1 shows the summary statistics of the word count for the students' responses. These results indicate that, on average, engineering students provided longer responses than geology students.

TABLE 1. SUMMARY STATISTICS OF RESPONSES

Tour	Question	Mean	Median	SD	Min	Max
Eng.	Liked	44.3	39.6	24.7	9.0	131.0
	Disliked	52.0	45.0	33.7	18.0	175.0
Geo.	Liked	14.1	14.0	6.8	1.0	31.0
	Disliked	12.7	11.0	9.6	3.0	55.0

First, sentiment analysis of the responses was performed using the VADER rule-based model [54], where the sentiment ranges from -1 to +1 (negative values represent negative sentiment). Table 2 shows the summary statistics of the sentiment analysis.

TABLE 2. SUMMARY STATISTICS OF SENTIMENT ANALYSIS

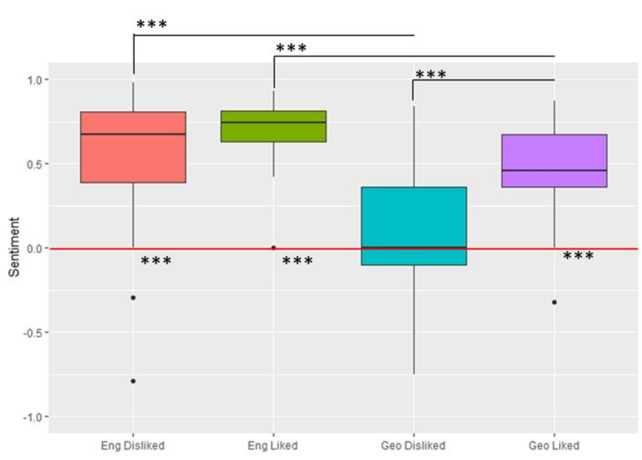
Tour	Question	Mean	Median	SD	Min	Max
Eng.	Liked	0.69	0.74	0.21	0	0.93
	Disliked	0.54	0.67	0.4	-0.79	0.98
Geo.	Liked	0.47	0.46	0.27	-0.32	0.87
	Disliked	0.06	0	0.38	-0.75	0.84

Figure 6 shows a series of boxplots of the sentiment of students' responses. A series of non-parametric t-test indicated that the sentiment of students' responses was, on average, significantly different than zero, with the exception of the responses of the geology students for what they disliked about the VR tour. Moreover, the non-parametric t-test indicated that the geology students' responses for what they liked about the tour had, on average, a significantly more positive sentiment than their responses for what they disliked. For the engineering students, while on average their responses were more positive for the questions of what they liked about the tour, there was no statistically significant difference between their responses.

Moreover, to identify the set of words that were more relevant to each of the students' group responses, the term frequency-inverse document frequency (tf-idf) was calculated [55]. The top-5 words with the largest tf-idf for each group response are shown in Fig. 7. From this figure, it can be shown that the words "engineering" and "campus" were the most relevant on the engineering students' response about what they liked about the VR tour, while the words "grand" and "canyon" were the most relevant for the geology students. Similarly, for the questions about what they disliked or could be improved about the VR tours the words "least" and "tour" were the most relevant on the engineering students' response, while "nothing" and "blurry" were the most relevant on the geology students' response.

Lastly, a semantic network analysis was performed for each of the students' group responses. Fig. 8 shows the semantic networks constructed from students' responses after removing English stop words. The top-5 bigrams of the engineering student's responses of what they liked about the VR tour were "close ⇒ ups", "vr ⇒ tour", "mechanical ⇒ engineering" and "tour ⇒ allowed". For the responses of what they disliked the top-5 bigrams were "vr ⇒ tour", "google⇒ cardboard", "3d⇒ photo", "actual⇒ tour" and "advance⇒ descriptions". For the geology tours, the top-5 bigrams of student's responses of what they liked about the VR tour were "grand ⇒ canyon", "cool ⇒ experience", "360 ⇒ degrees", "360 ⇒ rotation", and "activity ⇒ exciting". For the responses of what they disliked the top-5 bigrams were "bit ⇒ blurry", "bit ⇒ confusing", "bit ⇒ dizzy", and "bit ⇒ sick".

From these analyses, it can be concluded that students liked the VR tour. The engineering students liked the tour since it enabled them to take a tour of the mechanical engineering labs and see the different machinery that otherwise they would not be able to do due to COVID-19 restrictions. For example, students said "*I was able to see the labs as if I were there in person. It is much better than just seeing pictures of the machines. It made it more fun.*", "*I liked that I was able to get a glimpse of the Labs before going to Lafayette*", and "*I liked that we got a nice view of the space that we could potentially work in the future.*" Moreover, they reported liking the points of interest that contained images of the machinery and additional information about what they do and how they operate. For example, students said "*I liked how descriptions of each machine were shown throughout the tour - this was informative and helped me to*



Note: *** p-value<0.001

FIGURE 6. BOXPLOT OF SENTIMENT

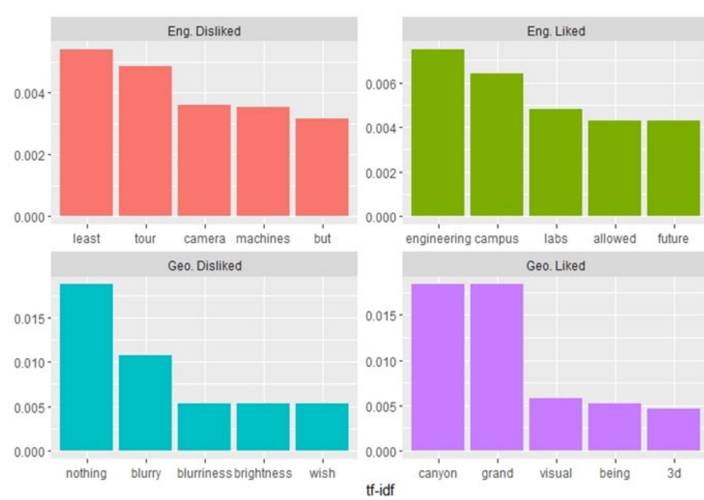


FIGURE 7. TOP-5 WORDS BY TF-IDF

FIGURE 8. SEMANTIC NETWORKS

understand each machine I looked at" and "*Most of the machinery had pop-ups on them that explained something about them, either as a whole, or the role of a specific part.*" Similarly, the geology students liked the VR tour since it enabled them to visit and experience unique 360-panoramic views of the Grand Canyon virtually. For example, students said "*I thought the visuals in the system were really cool and it made me feel like I was actually in the Grand Canyon*" and "*I like that it was very visual giving one person perspective feeling like you were there*"

Nevertheless, the most valuable information can be obtained when analyzing students' responses of what things they disliked or could be improved from the VR tours. For example, some engineering students reported that the google cardboard itself could be improved. This is because it is hard to align the smartphone on the cardboard correctly to avoid blurriness, which could induce simulation sickness. For example, students said "*No matter how long or how slowly I move when doing VR I always end up feeling very dizzy. This is probably due to the low tech google cardboard.*" and "*I did get a little dizzy when using the google cardboard, but the tour itself was alright*". The engineering students also reported that adding more detailed descriptions or videos of the machines would be helpful. For example, students said "*I believe there should be descriptions on more machines and some more detail*" and "*I think, if possible, adding like videos of the machines at work would be cool, like an active room rather than just the 3D photo.*" Similarly, the geology students express having issues with blurriness and dizziness, even more than the engineering students. For example, students said "*Sometimes the picture was a little bit blurry and had to hold the Cardboard away from my face to fine tune the picture*", and "*wish there was a good way to focus the blurriness of the app*".

While other low-cost VR headsets exist that might align better with a wider range of smartphone devices, it is important to recognize that some individuals are more prompt to simulation sickness than others. Nevertheless, it is important to provide clear instructions to students on how to align their smartphones to reduce blurriness, as well as how to detect potential signs of simulation sickness. The resolution and quality of the 360-panoramic images can have a direct impact on the quality of the user experience, this is because lower quality images tend to show more blurriness than high-quality images. This was evident from the responses of the geology students since the 360-panoramic ground-level images of their tour were not captured with high-definition cameras as in the case of the engineering VR tour.

6. CONCLUSIONS

Remote learning has already become a significant part of the education system and its enrollment will continue to increase in the future. Hence, educators need to improve the remote learning experience to be as engaging as traditional face-to-face learning. Educators can leverage VR technology to effectively engage students. VR use is limited because high-fidelity hardware and software systems are too expensive for schools. Alternatively, when using low-cost VR hardware (e.g., Google Cardboard), educators have limited choice of content (e.g., Youtube VR, Google Expeditions, RobotLab).

In order to help educators create VR content suited for their courses, this study provides a method that educators can easily replicate and modify. Educators can use a normal HD camera or existing aerial images to create panoramic images using image stitching software. Then a panorama will be annotated with information and navigation to guide the user through the VR tour. The tour is published and made available to the target device. This requires minimal skill from the content creator, and the materials involved are accessible to users; users already possess personal smartphones and low-cost VR headsets, like Google Cardboards, are available on online retail stores for just a few dollars. This method is feasible for in-person classes, fully remote, or hybrid classes. The results indicate that educators can employ low-cost VR headsets, especially in remote class environments to help increase student interest in learning and potentially increase academic performance. However, more testing is needed in order to draw conclusive findings about the effectives of these tours on student learning.

The proposed method has its own limitations including; stitching software producing poor output on plain images such as on the sky or walls, Google Earth Studio lacking 3D superimposition in some areas on the globe, and VR equipment causing simulation sickness in some users. For future improvements of the method, further testing can be done by creating more custom content for other STEM courses and testing it with more students. More interactivity can be also added to the VR tours. It is also important to investigate alternatives for the tools used at different stages of this method, (e.g., substituting Autopano for PTGui or using other VR headsets). Lastly, there is a strong need to mitigate the simulation sickness, and blurriness since this can have a direct and negative impact on user experience, which could ultimately affect students' perception of VR.

Future work should enhance interactivity of an immersive panoramic environment such as laboratories by adding kinematic mechanisms created in CAD into VR and allow the user to control moving objects. Other improvements can be focused on low-cost headsets such as Google Cardboard which induces motion sickness and can be blurry sometimes. However, advanced VR hardware can continue on the path of product improvements and decrease in price in order to make hardware accessible for schools.

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