Virtual Reality Mediated Instruction and Learning

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ABSTRACT

Several prominent media theories support the use of Virtual Reality (VR) in education, however, there are few examples to draw from due to barriers in implementation. Current generation, mainstream virtual reality systems have largely removed these barriers, allowing for evaluations to now take place.

The focus of this research is to identify the opportunities of VR interfaces with respect to how students learn challenging spatial concepts, and to discover what computer mediated communication in VR looks like in a classroom or lecture setting. In this study, we designed the VR software tools which instructors could use to develop their own style of lecture.

This paper follows the development process and the pivotal discoveries that led to the refined design modifications and implementation of our application called "VR Classroom". The results of the study provide a viable tool for instructors to create lectures in VR. The results also raised questions about how students could better learn in VR, how future technologies could solve these questions, and how the VR tool will grow in the teaching community.

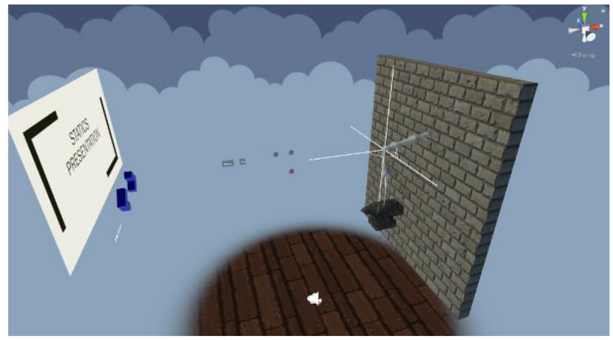

Figure 1: Components of VR Classroom. Imported PowerPoint on left side of figure. 3D model of engineering statics problem shown on right side of figure.

Keywords: Virtual Classroom, lecture recording studio interface, student's lecture viewer interface,

Index Terms: B.4.2 [Input/Output and Data Communications]: Hardware Architecture—Three-dimensional displays

1 INTRODUCTION

Educational virtual reality (VR) applications are a likely candidate for a large share of the consumer marketplace. One challenge to acceptance in this space is that there are few examples of how to teach and learn using VR outside of training applications, for example teaching math, science, or engineering. In this study, we prototyped a VR application that may be viable in this space, a tool for teachers to create lectures for engineering topics. This tool capitalizes on the real-world applications of engineering skills, which may translate better to the VR space, than other topics. The classroom can be viewed in *figure 1*.

Better understanding of how the teaching and learning affordances of VR technology could improve existing practices is critical for adoption. Studies have suggested that students may fail an education system because they do not master the symbol systems of the disciplines they study. [1] This may be particularly true in Engineering, which has an elaborate array of mathematical tools used to analyze and model systems. In a typical Engineering problem, students are often provided with diagrams that have real world analogues, but are presented as abstract 2D diagrams (e.g. vectors and moments) to "simplify" the presentation. This may prevent students from realizing where these models come from, and their relevance to solving real-world, 3D problems.

We believe that VR has a significant role to play in reducing this potential barrier for students in Engineering. One distinction of VR with respect to other media is that VR permits an immersive viewpoint. This viewpoint can be used to give students concrete visual experiences that would be difficult to achieve in a typical classroom. VR could enable, for example, students in Engineering to better understand how real-world structures and systems are modelled by first visualizing and interacting with realistic 3D representations.

VR and AR have been extensively studied in education, mostly aimed at how the affordances of VR may help students. One theory is that certain components of human cognition such as spatial skills lend themselves to VR education. Spatial skills encompass five main components including: spatial perception, spatial visualization, mental rotations, spatial relations and spatial orientation [2]; and, some evidence suggests that VR is a good tool for teaching spatial skills. For example, Kaufmann and Schmalstieg [3] created a flexible augmented reality system for teaching high school level geometry. This system provided an interface for teachers and students to interact together within the same real-world classroom. This study concluded that the tool was useful for teachers to use to teach students. Another, less resource-intensive application, the Desktop Virtual Reality Earth Motion System (DVREMS) [5] is an educational application developed for early grade school students learning components of the solar system. These sorts of systems help students better visualize 3D concepts, and are a direct way to include VR and AR in education.

A challenge, however, is that these applications and their content have almost been exclusively created by developers with input from teachers. This means that programmers are inherently in the loop, and that instructors can only create content that augments the virtual experience, rather than create new content or adjust the experience itself. This has been noted as a problem in the educational literature. For example, Richards and Meredith [4] have shown negative results in their evaluation of VR education. This study argued that VR simulations are impractical for the classroom as they require extensive programming to build

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and maintain learning experiences. Thus, we must be wary that a VR tool for education heavily rooted in programming may not lend itself well to the educational community.

Our approach is different from the systems above. We approach the use of VR in education as part of a virtual toolbox designed for teachers to prepare and deliver instruction that can be viewed by students in the same virtual environment. This would leverage interactive content, that could be used to create lectures that are unique from instructor to instructor.

Our concept is the VR Classroom. This application is designed to include all the benefits of teaching in VR while removing the complicated development processes that come along with creating an environment specific classroom experience. An example of the functionality of this type of application is Microsoft PowerPoint. PowerPoint allows users to create lectures on any subject without any knowledge of programming by integrating existing content with textual and graphical annotations. VR classroom is an extension of this concept into the interactive 3D space.

The idea for this type of application came from precursors like Google's VR application *Tilt Brush*. In *Tilt Brush*, artists can paint in 3D space. The brush strokes are recorded and can be played back to a viewer. In this way, the artist acts like an instructor and can use VR as a tool so that a viewer can learn how to paint a 3D image by watching the artist work. This artistic lecture takes the form of recorded 3D spatial video that can be viewed from every possible angle. Like Tilt Brush, VR classroom provides flexible 3D annotation tools, but specifically those that are useful to instructors of a particular topic and cater to lecturing.

By taking this approach, we can empower new and old forms of teaching and learning. For example, there is a theoretical division in learning preferences and teaching approaches known as inductive learning and deductive learning [6]. In inductive learning, learning is based on discovery, and inquiry, starting with activities for students that are later discussed with an instructor. By contrast, deductive learning concentrates on starting with fundamentals through lecture followed by activities to explore concepts. VR applications, such as DVREMS would fall under the category of inductive learning, which is highly popular as a modern, active learning technique. Many instructors still follow the deductive approach, however, as it may be a more efficient pathway to learn large amounts of material. Our tool facilitates this with modern technology, i.e. traditional teaching in a modern way. As in PowerPoint, instructors can bring in external resources (e.g. images, videos). Also, there are large repositories of resources that can be used in a classroom setting that would create rich environments for communities of teachers and students to interact. These resources include 3D models and virtual environments [7]. The difficult task for instructors and the tool, is to enable the creation of effective lectures using these resources.

In this paper, we discuss the design of the VR classroom and study the suite of functionality that instructors would like from such a tool. The focus of the study is to create a tool for instructors to create lectures. With this focus it is important that the tool allows instructors to create unique lectures in their own style without the intervention of developers. By delivering enough tools that can be used within VR Classroom, we believe instructors will be able to create their own unique lectures without programming knowledge and that the VR Classroom can be widely adopted by the teaching community.

2 Hardware

The VR classroom is designed as an application for a room-scale immersive virtual reality platform. This platform closely matches a classroom sized space from an instructor's perspective, and provides virtual space for many types of content to be displayed simultaneously. The particular platform we targeted is the HTC Vive Virtual Reality Headset and accessories. This package includes the head mounted display which provides two screens, one per eye, with resolutions of 1080x1200 and a field of view of 110 degrees, head position tracking within a 15-by-15-foot tracking space courtesy of a microelectromechanical system, gyroscope, accelerometer and laser position sensors, and two position tracked wireless controllers. This platform acts as the peripherals for a desktop PC running the Virtual Classroom application built within the Unity3D engine.

Careful consideration went into the platform selection. The HTC Vive platform does not provide the level of accessibility that would be desired for consumer educational product. Other platforms such as the Google Pixel smartphone and Google's Daydream View HMD are more accessible in the consumer marketplace however, they lack specific features that are imperative to the functionality of the type of application we are trying to create.

The most important feature that the HTC Vive peripherals includes is (6-DOF). With respect to head tracking this gives the user complete translational viewing angles. In mobile phone VR systems, the user's head is connected to a single position in space and rotating the head to look around is the only degree of freedom permitted. With the HTC Vive, the user can translate their head in any direction and look at an object from any angle. This feature is essential in the VR classroom where we are attempting to build where head translation allows the user to view immediate proximate objects from every possible angle.

In addition to head tracking, the wireless controllers that are part of the HTC Vive peripherals are equally important. The wireless controllers serve as the user's hands in the virtual environment. The instructor's hands provide several important functions in a lecture setting. In addition to tracking hand position, the controllers also have a touchpad and buttons that can serve as various control functions for both the lecturer and the viewer. While Bluetooth gamepads can be used in conjunction with technologies such as mobile phone VR, they do not offer the degree of freedom and position tracking that is required for the VR Classroom application.

Similar products to the HTC Vive are the PlayStation VR and Oculus Rift. Both platforms are similar in that they offer (6-DOF). The PlayStation VR is more accessible to consumers due to its price point range; however, it is tethered to its PlayStation 4 console making it less accessible to developers. Furthermore, the tracking system known as PlayStation Move uses light and cameras to track position and offers the least precise position tracking of the three platforms. At the time of building the VR Classroom application, the Oculus Rift did not have any hand tracking peripherals but has just recently released their own position tracking controllers. The Oculus Rift is currently very similar specification wise to the HTC Vive and is a viable platform option for future development. While these platforms meet the specification requirements of the type of application we are attempting to create, there is still a bridge between what is easily accessible to a student and what features are required of the VR Classroom application.

Looking at current technology trends, we can also predict some near future technologies that would serve as ideal platform candidates for the VR Classroom application. These near technologies could have the specifications required of the VR Classroom application as well as having the accessibility that would be required to make this a valuable tool to the public. One such product that shows promise is Google's Tango. This product is a mobile device containing two cameras that map your current room in 3D space. This single device operates like other VR mobile HMD but can afford (6-DOF) and could have the same accessibility to the public as mobile phones have in the marketplace today. Given time to develop and grow in the consumer marketplace, this is an accessible device that could meet all specification requirements of our study's application within the near future.

3 Application Design

To design the application, we followed a strategy of prototyping and iterative review by a single static lecturer, familiar with teaching many statics engineering courses, and focusing on a problem in Engineering Statics. The statics problem of focus is depicted in *figure 2* in its traditional textbook 2D diagram. The problem introduces students to a new concept of moment vectors. Students must solve for the moment vector that passes through points *OA*. In doing so, they will discover tangential position vectors along the line of action and the force vector created by the weight of the potted plant. It is difficult to conceptualize these vector angles in a 2D diagram. The advantages of working in 3D are a better spatial understanding of the model which is obtained from a VR environment.

A better spatial understand of the model can be obtained by bringing the model into the real world, however, this is not always practical. Additionally, even if the 2D diagram is brought into the real world there is still no way to draw on the model. To teach the concept, our teacher is tasked with drawing vectors in 3D space which is achievable in a VR environment. There are several tools that our teacher requested to be able to teach this concept to students in VR. These tools included the ability to draw vectors in 3D and have these vectors snap to the diagram, the ability to annotate the 3D model, distinguishable force vectors and moment vectors, the ability to draw a 2D plain in 3D, and the ability to import PowerPoints into the VR environment. Finally, the application must serve the function of recording and playback to enable instructors' efficient delivery of lectures.

After several iterations of prototyping, a product was delivered that was capable enough for our instructor to teach students how to solve this particular statics problem. The interface designed is optimized for the teaching experience as well as for students to view a lecture created by instructors. The interface is designed as follows.

The main interface of the VR Classroom application is the 3D virtual environment. From this environment both lecturers and students use all components of the application. To interact with the system the user wears the HMD of the HTC Vive and holds the wireless controllers to interact with the virtual environment. The use of the application can be broken down into two subcategories which include the "lecture recording studio interface" and the "student's lecture viewer interface". The first subcategory of the application that we will discuss is the lecture recording studio interface.

From the lecture recording studio interface, the instructor can record a 3D spatial and audio recording of everything they do in VR Classroom. The instructor's controllers and viewpoint are captured by the recording software. This study focuses on an instructor teaching engineering statics concepts in VR Classroom. In the virtual classroom, there exists a 3D model of a typical statics problem see *figure 3.* Using the recording software, the instructor's microphone, and virtual hands the instructor can point to areas of interest on the 3D model and explain concepts for

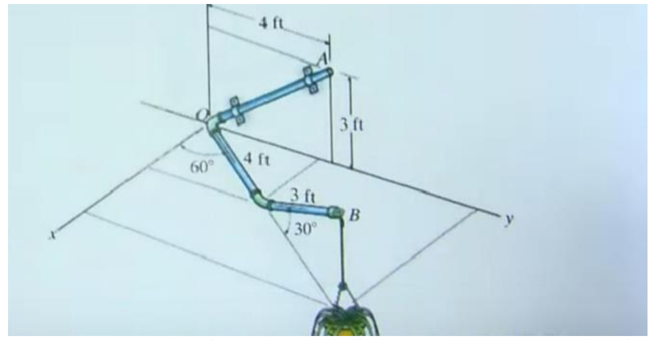

Figure 2: Example of 2D diagram of statics problem. Example of traditional textbook approach to spatial description.

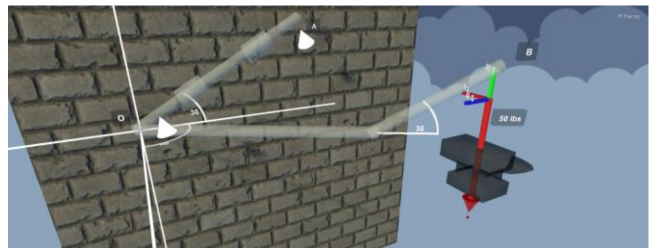

Figure 3: VR Classroom approach to same problem. Immersive viewpoints allow viewer to analysis from any angle.

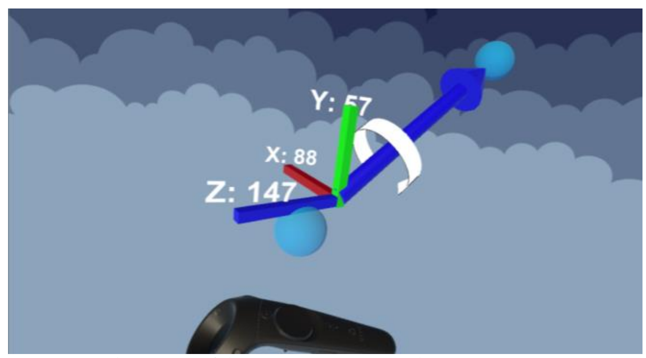

Figure 4: depiction of line moment vector drawn in 3D space. To illustrate rotation of moment vector there is a white arrow that rotates around the blue arrow.

auditory and visual learning. Later, a student can watch this recording and see where the instructor is looking in the 3D world. The student can hear what the instructor is saying and they can see what the instructor is doing with their hands.

Furthermore, by using buttons on the wireless controller, the instructor has access to navigation menus that provide various other tools. These tools are specifically designed to help teach engineering statics concepts. By navigating the menus in VR Classroom, the instructor can select and place a line vector in 3D space see *figure 4*. This is a useful tool as it helps the instructor to demonstrate how force vectors effect the static system. Other tools at the instructor's disposal include measuring tools so that the instructor can determine distances and angles on the 3D model. Like how one might approach a real-world statics problem, the student can watch the instructor solve the problem by measuring components in 3D space.

In addition to features included in the menus, there are other components of the virtual environment that the instructor can manipulate. Upon starting the recording, the instructor has access to labels which they can move and place onto the 3D model. This helps with labelling coordinates and areas of interest. There is also a large screen on one side of the virtual classroom. This screen displays PowerPoints that are imported into VR Classroom. By tapping arrows, the instructor can scroll through a PowerPoint that they have prepared before their lecture. These features combined create an ideal classroom for an instructor to teach engineering statics concepts.

The other subcategory of this interface is the student's lecture viewer interface. A student can wear the HMD like in the previous interface and select recording playback to view a 3D spatial recording of the lecture previously created by our instructor. From this interface, the student can hear all the recorded audio of our instructor as they explain the concepts of statics from an auditory learning perspective. The student is positioned in the middle of VR Classroom with a 3D statics model in front of them and a PowerPoint screen behind them.

The student will first notice the instructor's recorded hands that draw attention to points of interest. Originally, the instructor looking at their own hands would see the controllers as well as navigation menus. Now, the student viewing the recording only sees white arrows as the instructor's hands. There is a certain level of information hiding in these two interfaces and it is only essential for the student viewing the recording to see where the instructor is pointing with white arrows. These white arrows follow all the recorded motions of our instructor's previously recorded lecture. The instructor's hands act as pointers guiding the user's attention to areas of interest determined by our instructor in their lecture.

The student watching the 3D spatial recording can also see the tools that the instructor is using in their lecture. As the instructor uses tools like the force vector arrow, the same line appears before the student. As the instructor changes the slide of the PowerPoint in their lecture, the student viewing the recording sees all the same changes. The added benefit of the lecture viewer interface is that the student has 6-DOF. They can change their perspective in any way and can re-watch from any angle the points of the lecture that are unclear or need reiteration.

As previously mentioned, the VR Classroom application requires the use of a VR ready PC and HTC Vive platform. Unfortunately, these peripherals are not easily accessible to consumers. To make the student's lecture viewer interface more accessible, the lecture can be viewed from a PC. Students of the VR Classroom can view the recorded lecture on their PC. Mouse and keyboard are used to shift angels and view a lecture from any desired angle like 3D modelling software interfaces. Although less immersive than VR, this interface is easily accessible and still provides benefits of 3D and changing perspective.

4 FORMATIVE STUDY

In this study, one statics instructor was responsible for the iterative design process. This instructor was the main resource for all the tools that would be needed to teach the statics concept. This instructor was recruited within the university and had many years of statics teaching experience and previous experience with VR and AR technologies. On a weekly basis, the instructor would interact with the application and provide input on the tools that would be needed to teach a specific type of lecture. Tools were then created and added to the application for the next review by the instructor. Once the application reached a point where our professor believed that the entire lecture could be taught in the virtual environment a full lecture was recorded.

After the application had been built and a lecture had been recorded, a second statics instructor was introduced to the application to review the design of the application. This second

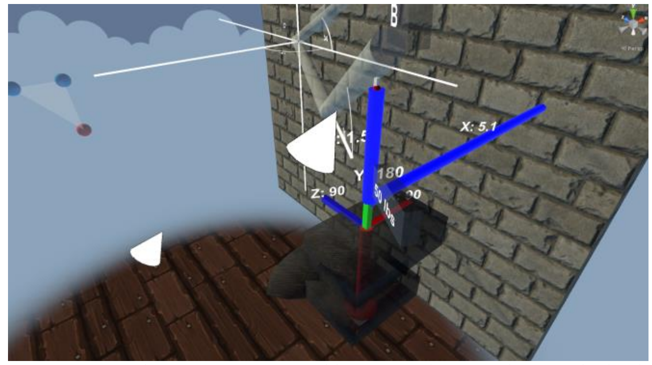

Figure 5: White pointers are visible to a student watching a playback. These represent the instructor's recorded wireless controllers and point to areas of interest.

instructor also had many years of experience teaching statics material and was selected from the same university. The second instructor was introduced to the VR Classroom and all the details of the project were explained. The second statics lecturer then took the role of a student and watched the lecture that had been previously recorded. After viewing the lecture from a student's perspective, the second statics instructor was interviewed for feedback on the system. This additional viewpoint provided insight in determining how one instructor's preferences would translate to another's and what additional tools might be required. In the review, the second instructor provided initial impressions of the system, input in how they would use the system differently in their own style of lecture and input for future development.

The introduction of another statics instructor's perspective introduced a very different teaching style and a new method for solving the exact same problem. Our first instructor solved the problem using a cross product between the moment vector and force vector. Our second professor explained that in his lectures he focuses on a tangential resultant vector and how its shape in 3D space could be used as another method to solve the problem. Despite having a different approach to solving the problem the second instructor did believe that he would be able to teach his unique concept in the application without making any modifications to the application and using the tools provided. He did suggest a new tool to include in the application that would make teaching his concept easier. He described a vector that could be drawn in 3D space that acted as a calculator that would automatically draw a resultant force.

The review of the application by a second perspective was positive confirming that this would be a valuable tool to students. Initial feedback was positive stating that this type of application could alleviate spatial learning barriers. There were no believed disadvantages with using this application juxtapose with traditional teaching methods. Additionally, initial feedback reaffirmed that other teachers would be able to leverage the application as a tool to create unique content. The second instructor believed that he could use the tool in its current state to teach other statics concepts that are part of the curriculum. He believed he could do this without making any functionality changes and by using the current tools provided.

In watching a completed lecture, the second instructor also assumed the role of a student. Results from the student's lecture viewer interface introduced some initial concerns. From the student's lecture viewer interface, the student did not always follow were the teacher was attempting to draw attention. The teacher would highlight areas of interest with virtual pointers *figure 5* and shift attention using audio commands however, these measures were not always effective in drawing attention. This is attributed to a learning curve associated with using VR for the first time. Feedback from our second instructor suggested better tools for the teacher to get the attention of students in the virtual environment. Furthermore, feedback from both instructors included that a student using the VR system should have an ability to take notes for future reference without having to re-watch the entire lecture. It was suggested that providing students some type of audio recorder within the application would allow them to take short audio notes while watching the lecture.

There were two layers to the study. The first layer was to design VR Classroom as a base tool for instructors to record lecture in VR. The second layer of the study was a static lecture that was a prototype of a classroom lecture. By building out the statics lecture on top of VR Classroom many discoveries were made in regards to the design of the application. These discoveries included usability and what type of lectures the application is most suited for.

In terms of usability, having precision and including the ability to annotate in a virtual environment was a challenge. As part of the instructor's requirements for the statics lecture they must be able to accurately place force vectors on the 3D model. It is difficult to have the level of precision necessary in placing a force vector to teach a concept in VR. To aid in this problem snap points were introduced to the 3D model which allowed teachers to quickly and accurately draw vectors on a 3D model. Additionally, our instructors require an ability to annotate in VR to teach statics concepts. In a traditional 2D chalkboard model, an instructor would annotate a problem by drawing on a chalkboard. In a VR environment, it is difficult to write with the wireless controllers in 3D space [8]. An alternate solution was developed for annotating in VR. Outside of the application instructors added annotations as tags using a desktop interface. Once our instructor entered the application they could drag tags onto the 3D model and annotate key points. An example of this is that our teacher wished to label coordinate points of the 3D model within the application. To accomplish this, they could enter the VR Classroom and drag and drop tags onto the 3D model that they had already created on their desktop. Solving these various challenges in respect to a statics lecture has helped to develop the base VR Classroom. Future work can expand upon these principals to create a more versatile tool for teaching many types of subjects.

5 Conclusion

VR has distinct advantages from an educational perspective. Most educational content created for VR consists of guided experiences created by developers to teach specific concepts. The distinct difference in the VR Classroom application is that it embodies a tool for teachers to create unique content in VR. Teachers can focus on the content and not the development. This study attempts to define the functionality of a VR Classroom as a tool for teachers.

To test VR Classroom as a tool for teachers, we built the application in the context that it would be used to teach an engineering statics class. In building a lecture on top of VR Classroom, discoveries where made in regards to how VR Classroom should function as a tool. We discovered that the tool must record imported 3D objects for demonstrational purposes. VR Classroom must also have the recording capability to capture specific tools that a teacher may use in a lecture.

At its most fundamental level, the VR Classroom is a lecture recording studio. Easy to implement is a 3D spatial recording system that can capture 3D objects. Additionally, the open source community consists of copious amounts of free 3D models that teachers can import into their VR Classrooms. However, there are many required tools that include additional functionality outside of recording simple 3D models. The example includes the ability to import PowerPoints into VR Classroom. As VR Classroom grows, it must contain a very standard Software Development Kit (SDK) for recording. Teachers need a variety of tools and having a standard interface for 3D spatial recording in VR would allow developers to build a repertoire of tools in addition to recording 3D models. Virtual tools can then be continually added to a software library. All teachers in the community can then reference this library repository and pull tools into their VR Classroom to create unique lectures. This would provide a basis for an open source VR Classroom that can grow for the teaching community. In accomplishing these factors, VR Classroom will become a versatile tool for instructors instead of a single educational demonstration in VR.

6 Future Work

This study is a work in progress. The feedback provided from subject matter experts has been instrumental in building VR Classroom; however, a study using student participants is still required to determine the effectiveness of a VR lecture. A study using student participants would provide the feedback needed to build out and enhance the student lecture viewer interface portion of VR Classroom.

Emerging technologies in the rapidly expanding world of VR can also address initial concerns in VR Classroom. Adding the ability for students to take notes in lecture could be solved with future work in augmented reality (AR). Instead of utilizing a VR Classroom an AR Classroom could place a lecturer, 3D models, and tools in the middle of a real-world room. Students would be able to view the lecture as well as the physical world. AR technology would facilitate 6-DOF in a lecture and permit students to take notes with real-world pen and pencil.

Future work could expand upon ideas of AR and additionally make virtual classroom more accessible. While the currently available Microsoft HoloLens would lend itself to this idea of an AR Classroom, it is currently a very inaccessible tool. As previously mentioned, Google's Tango works as a mobile viewer and could facilitate an AR Classroom. Further study will expand upon the ideas of VR Classroom as a tool for instructors and adapt to emerging technologies such as developments in AR.

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