DEVELOPMENT OF AUGMENTED AND VIRTUAL REALITY

ENVIRONMENTS FOR USE IN ENGINEERING

GRAPHICS EDUCATION AT CSU CHICO

A Project

Presented

to the Faculty of

California State University, Chico

In Partial Fulfillment

of the Requirements for the Degree

Master of Science

in

Environmental Science

Professional Science Master Option

by

Charles J. Pooler

Spring 2016

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DEDICATION

I would like to dedicate this work to the friends and family whom supported me in this endeavor. Specifically, my loving wife Angela, our two children, Harper and Ella, my mother and father Cathy and David, as well as my friends Dr. Joseph Greene and Dr. Daren Otten. Your encouragement is what made this possible.

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I would like to thank my committee members, chaired by Dr. Joseph Greene, and consisting of Dr. Daren Otten, and Mr. Jeff Underwood.

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I could not have completed this project without the help of Steven Vaccari who was the student instrumental in developing the virtual reality components of this project. Steven is an extremely bright student who was wonderful to work with. I could not have been happier with my experience with my friends and faculty affiliated with the Chico State Computer Animation and Game Development Major, and I look forward to future collaborations concerning augmented and virtual reality projects.

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There has been increased attention by researchers and educators in *science, technology, engineering, and math* education (STEM) to develop the next generation of scientists and engineers. These future technical professionals will be tasked with the responsibility to advance our global society, and must be able to adapt to our ever increasing level of technological sophistication. In order to develop the skills necessary for these students to thrive in a technologically diverse industry, incorporation of computer technology has shown promise in the development of the less discussed engineering related “soft skills.” Traditionally, these engineering soft skills were defined to encompass areas that concern skillsets pertaining to presentation skills, report writing, teamwork, and working in teams. Early on, in undergraduate engineering education,

engineering graphics courses are tasked with infusing introductory engineering curriculum with activities that enhance these engineering students' soft skills. Topics in engineering graphics include a range of concepts which may incorporate project management, the preparation of professional presentations, and the effective use of hand sketching and the use of *computer aided drafting* (CAD) software packages. For students to master CAD software platforms they must be able to visualize the intended object and relate this object's technical information to a virtual computer generated file. Over time, researchers have come to understand the importance of a student's ability to mentally visualize and alter an object in their mind. As a result, researchers have included the development of these spatial skills into their list of essentials concerning engineering soft skills education. These spatial and visualization skills remain to be a vital skillset for numerous disciplines outside of engineering and in previous research, among other things, have been linked to a student's ability to master CAD platforms.

The results of these studies led the way to additional research and the concept of the implementation of spatial training in higher education to develop a student's spatial skills. Initially the spatial training regimen that students followed entailed several types of problems that would comprise of object rotations, revolves, planes of symmetry, and so on. These problems were presented using traditional two-dimensional media via textbooks or worksheets from their instructors. Recent advancements in technology are now allowing educators the ability to manipulate lessons like these and present them in a virtual, three-dimensional environment through the use of augmented and virtual reality technologies.

It is the added three-dimensional element of spatial skills development that has sparked the interest of researchers and educators alike to be used as a teaching tool to enhance the traditional understanding of a student's learning environment. Previous studies that concern the development and use of augmented reality in engineering graphics education have been conducted and deemed significant but the educational environment has not been able to keep up. In addition, there is little information on the development and use of virtual reality learning environments in engineering graphics courses due to the complexity involved in the creation of these complex files.

This project examined the use of augmented and virtual reality media's potential role, to enhance a graphical communication course in undergraduate engineering education at CSU Chico. The use of augmented reality is becoming more common in engineering education, with the first textbooks now coming available that use the digital media in conjunction with graphical education instruction. In comparison, the use of a virtual reality learning environment remains elusive at best, due to the complexity and cost associated with the included technology. Based on the current state of the environment and the uncovered information, this *Professional Sciences Master's* (PSM) project has two areas of concentration. The first emphases on the development and use of my own augmented and virtual reality files to be used in undergraduate education using SolidWorks® and Augment® augmented reality software. The second milestone is to create an inexpensive virtual reality environment for a diverse student population to be employed in the classroom. This project component required the use of the solid modeling software SolidWorks® to create virtual parts, that needed secondary finishing operations in a software package called MeshLab®, to be imported into the Unity® 3D gaming engine for rendering into virtual reality compatible file types. Following the development of these files, the creation of dynamic virtual environments was created for the students to view and use, to expose them to multiple perspectives not previously available in traditional two-dimensional media. Earlier research has shown that by exposing students to a virtual environment with the ability to manipulate and engage in their work, students experience enhanced retention through hands-on learning while simultaneously increasing student motivation in the presented material.

Previous research conducted on virtual reality in education evaluated more expensive, and hard to obtain virtual reality headsets. These headsets are unpractical for student use. With virtual reality becoming mainstream, more compact and economical equivalent platforms are coming out almost weekly. To cater to a diverse student population, the development of an inexpensive *Head Mounted Display* (HMD) was pursued using cheap, readily available, off the shelf components for student use.

In addition to the virtual reality component, the use of the augmented and virtual reality files was pursued to enhance engineering graphics instruction. The incorporation of augmented reality media would assist in teaching as well as aid in developing the spatial skills of required of science, technology, and engineering students. The emphasis of this project paper was to create a methodology for an engineering graphics faculty member to develop these files and environments smoothly, and to distribute these files to their students to aid in their spatial visualization skills development. It has been shown that the use of augmented reality has shown considerable dexterity. Its application as an effective teaching tool has been evaluated outside the college of engineering, to enhance the learning environments of numerous grades and disciplines spanning from engineering to anatomy, and from kindergarten to graduate education.

CHAPTER I

INTRODUCTION

The purpose of this project was to create and implement augmented and virtual reality media in an introductory engineering graphics course at California State University, Chico (CSUC). Creating these files and the development of the associated curricula was the primary concern of this project. The implementation of a spatial visualization assessment tool to evaluate the effect that the inclusion of augmented and virtual reality media has on spatial visualization development in undergraduate engineering students enrolled in Engineering Graphics MECH 100 Lecture will be pursued in future research.

Background

This project was designed to implement advancements in augmented and virtual reality environments to be used in an introductory engineering graphics course at CSUC. The intent was for the researcher to become familiar with these technologies and to investigate the effectiveness of these technologies to be used as tools to develop an engineering student's spatial visualization skills. Through the use of this content, students are exposed to a computer generated world that either augments their learning environment's surroundings, or in the case of virtual reality, elicits a sense of presence in a virtual world. The project will investigate the impact that previous studies have had on the use of augmented and virtual reality technologies' ability to motivate students. To aid in the successful implementation of these computer generated environments, the project will involve research into similar studies and applications of these technologies to create the project scope and the project deliverables. By referencing previous studies and research of successful applications of augmented and virtual reality in undergraduate engineering the researcher will apply the collected information to form augmented and virtual reality environments to be used in an introductory engineering graphics course at CSUC during the Spring 2016 semester.

Mixed Reality Media

Mixed reality encompasses the integration of real and virtual environments that create digital representations of objects may be acted upon physically by a user in real time. For the purposes of this paper, the term mixed reality will also be used to refer to both augmented and virtual reality environments. The conventional interpretation of *Virtual Reality* (VR) involves one where the user is totally immersed in, and able to act upon a synthetic environment (Milgram & Kishino, 1994). The definition of *Augmented Reality* (AR) involves a blend of the real world environment, augmented by means of computer generated content tied to specific locations and/ or activities (Yuen & Johnson, 2011). As the proliferation of mixed reality technology continues, its use is being investigated for ventures outside of the realm of entertainment. In recent years, educators and researchers have been evaluating mixed reality's role in enhancing instruction and increasing student motivation (Lee, Kok, and Fung, 2010).

The effective use of technology in the classroom is not without its complications. For a smooth transition from conventional media and teaching tools, to augmented and virtual tools, there must be a substantial amount of work done in part by the course instructor. These instructors must acquire an interdisciplinary knowledge base to conceptualize, create, and manipulate mixed reality media in a manner that enhances the classroom learning experience, and does not take away from it. The integration of mixed reality media needs to complement the course material, not complicate them.

Mixed Reality Media in Engineering Graphics

One of the best applications where mixed reality can compliment instruction is its use in undergraduate engineering graphics courses. Traditionally, engineering graphics courses involve introducing entry level engineering students to concepts in engineering graphical communication. These topics can vary from course to course, but surely include the use of standardized drafting methodologies to present detailed engineering information in a graphical form via two-dimensional working drawings. The creation of these drawings require the development of the associated engineering student's spatial skills, in the creation of accurate depictions of their intended designs. These spatial skills are developed by directly addressing them via tailored visualization specific exercises and curses or passively, through the student's use of a CAD software package.

The use of CAD software alone can enhance the spatial skills of engineering students. When CAD is used as the sole source of spatial skills training it may not be enough for some students whom are struggling with their spatial skills. If one of the key learning outcomes in engineering graphics is to advance their capacity to communicate ideas graphically, then it would make perfect sense to implement three-dimensional mixed reality media to aid in the development of their spatial visualization skills. This mixed reality media allows for the integration of a three-dimensional element in engineering graphics communication vs. the traditional two-dimensional traditional restraints. Through hands on learning in a three-dimensional virtual learning environment, students may be able to better understand and retain the presented material than with traditional two-dimensional learning environments.

Spatial Skills

To ensure the effectiveness of a college level course, instructors implement *student learning outcomes* (SLOs) in their syllabi. These SLOs are the concepts and elements that students will be exposed during the progression of the course and as the criteria to be used in the assessment of their students' educational advancement during the semester. To ensure that students fulfill the associated course's SLOs, checks and balances must remain in place to evaluate and investigate each students' development. Since spatial visualization skills have been identified as a factor in their potential success in mastering CAD software, then spatial visualization skills must be addressed somehow in engineering graphics student's SLOs. Previously, spatial visualization skills were developed indirectly. These skills will be advanced throughout the progression of an engineering graphics course by completing exercises involving hand sketching and by sometimes, simply by using a CAD software package. In the past, spatial skills were passively addressed. Recently, these skills are being brought to light due to the recent research that illuminates the links between spatial visualization skills and engineering student success. Due to complications like this, topics like visualization may not have been directly addressed let alone assessed, compared to the more traditional engineering "hard skills" like the advanced understandings of mathematics, science, and physics. These "hard skills" are relatively easy to test by administering traditional testing tools. More thought is required on the part of the instructor to accurately evaluate a student's spatial and visualization skills.

One of the most accurate methods to assess an individual student's spatial abilities is through the *Purdue Spatial Visualization of Rotations* test or PSVT: R. The PSVT: R was developed by Roland Guay in 1977 and based on the literature review, remains one of the best means to obtain an accurate spatial skills assessment. The PSVT: R is a 20-minute timed test which consists of 30 multiple choice questions that involve mental rotations of presented objects about one or two axes. The passing rate for the PSVT: R is 60%, where students that fall below this threshold would benefit from additional spatial visualization training. The test can be administered as a pre and post-test to assess student's progression through their respective spatial visualization courses or in this case, treatment programs. By administering the test in this fashion, researchers or instructors have ability to gather baseline scores and compare them following the conclusion of a course, to better assess if learning outcomes in spatial visualization have been adequate or inadequate.

Traditionally, courses like engineering graphics are difficult for some students to master. Courses like these require the development and understanding of both the addressed engineering soft and hard skills. In previous research, some groups of students have been shown to have more developed spatial visualization skills vs. others. How these differences occur are a source for debate and may range from personal to environmental factors. For example, similar to other measures of spatial visualization abilities, the PSVT: R sheds light on gender differences regarding mental rotations. Research illustrates that spatial visualization tests like the PSVT: R favor males. If spatial visualization skills are essential to engineering student success, then early spatial assessment and intervention in an engineering program may help prevent student frustration or drop-outs, enhance student diversity, and increase engineering graduation rates. The use of the PSVT: R will be investigated for its effectiveness in assessing spatial visualization skills and its future implementation into MECH 100 Lecture will be the subject of an ongoing research project.

Purpose of the Project

The purpose of this project was to build upon established research on the use of mixed reality in engineering graphics courses and apply it at CSUC in an introductory engineering graphics course. There has been substantial research into the utilization and integration of augmented reality in the classroom to enhance engineering education, but undergraduate engineering education has been slow to adopt these technologies. This project investigated the creation of both augmented and virtual reality environments to be delivered to a diverse student population. Future research will be conducted on the data collected during the course of this project to examine the role that mixed reality may have had on enhancing the spatial skills of students, as well as how the use of this technology may have influenced their motivation and engagement in an introductory engineering graphics course. Similar studies have been conducted nationally but none that specifically concern the engineering students enrolled at CSUC.

Scope of the Project

The project elements were created and implemented over the Spring 2016 semester at CSUC in the MECH 100 Lecture portion of the Engineering Graphics I course in the Mechanical and Mechatronic Engineering and Sustainable Manufacturing Department located under the umbrella of the College of Engineering. Given the research on spatial visualization skills and student success, both traditional two-dimensional and mixed reality spatial skills training were incorporated into the semester's weekly discussions. In addition, the engineering graphics curricula was assessed for areas where augmented reality could substitute traditional two-dimensional media. As a result, a new textbook was selected that utilized augmented reality as a part of the instruction. This text was designated in the syllabus as "recommended" for the class. In addition to the new text, spatial visualization interventions using augmented reality were created to be utilized in assigned Engineering Graphics I homework. This process entailed the conceptualization of a solid model, the creation of these solid models in SolidWorks® CAD software, importing them into an augmented reality software application known as Augment®, creating an augmented reality marker, and applying these augmented reality files within the associated MECH 100 Lecture assigned homework.

To fulfill the mixed reality component of the project the engineering graphics curriculum was assessed for areas where the use of virtual reality environments may be applied to aid in Engineering Graphics I instruction and to help develop the enrolled engineering students' spatial visualization skills. Given that one of the barriers to adopting the traditional virtual reality environments in instruction was the high cost required for equipment, a low-cost virtual environment was pursued to cater to a diverse student population. The pursuit of a low-cost virtual reality environment consists of a low-cost cardboard headset, a student provided Android® smart-phone, and a software application that could accept and render a CAD generated solid model to present to the student in a graphical user interface.

Finally, student success as a result of spatial visualization training must be assessed to determine the role that the incorporation of mixed reality technology may have on engineering student success. The PSVT: R will be investigated and administered as a pre and post-test to determine if these types of interventions have an impact on engineering graphics students' spatial visualization skills. The focus of this project remains the investigation, creation, and implementation of augmented and virtual reality media in an introductory graphics communication course. The analysis of collected data, concerning student surveys and the pre and post-tests of the PSVT: R, will be presented in future studies. The PSVT: R has never been administered to incoming freshman engineering students at CSUC. As a result, the data collected can be used to establish a baseline of incoming engineering students' spatial abilities.

Significance of the Project

The primary significance of this project involved the inclusion of augmented reality media in the MECH 100 Engineering Graphics I classroom, and the development of an inexpensive virtual reality environment for student use. During the literature review, the importance of the PSVT: R and its use as an accurate spatial visualization assessment tool were uncovered. This test was administered to the students in MECH 100 Lecture for their own benefit, and upon clearance from the Instructional Research Board students whom wish to participate in an ongoing study will allow the researcher to assess the impact that augmented and virtual reality media may play in student motivation and spatial visualization skills development. This information may convince the College of Engineering Administration of the importance of the PSVT: R, and may influence them to provide this assessment to all incoming CSUC engineering students.

The primary concern of this project is to develop and investigate less traditional augmented and virtual reality teaching materials for use in undergraduate engineering education. Augmented reality technology is becoming more user-friendly from the perspectives of both students and educators. As a result, augmented reality is now finding its way into more and more classrooms. Virtual reality still remains more illusive due to the high costs associated with the expense of hardware, and the complexity of the software required to generate the associated three-dimensional environments. This project is significant in that it will require interdisciplinary collaboration to develop the mixed reality media, which will be released for student use in engineering graphics education at CSUC. For the purpose of this PSM project, these mixed reality environments will be used to help enhance engineering students' spatial visualization skills, while hopefully attributing to engineering student success.

Limitations of the Project

The incorporation and implementation of mixed reality media in the classroom requires an in-depth knowledge that spans multiple disciplines. The development of CAD files in SolidWorks® requires software specific knowledge that takes several years to master. This is also the case for some augmented and virtual reality software packages. Students whom identify themselves as a student of engineering may possess technological skills that exceed the average adult, but the knowledge required to generate a three-dimensional computer generated augmented or virtual reality file requires familiarization to an entirely different and unique series of hardware and software packages. One of the biggest limitations that most instructors are forced to face in the implementation of mixed reality media is obtaining this interdisciplinary knowledge.

To compensate for this inadequacy, the researcher looked for help from the *Computer Animation and Game Development* (CAGD) program here at CSUC. The program is unique in the CSU system and provides students with the foundation of creating three-dimensional media using advanced game engine software packages. After making contact with faculty in the CAGD department, CAGD faculty offered to advise on the PSM project and allowed for one of their pupils to help with the virtual reality component of the project. Through discussions and meetings with the CAGD student and with help from the CAGD faculty committee member, the project was able to move forward with the development of an inexpensive virtual reality environment for student use.

With the intention of developing an inexpensive mixed reality learning environment for students, another concern included the inclusion of the required mobile device technology to download and run the augmented and virtual reality software. The student population will be required to supply their own mobile devices for augmented and virtual reality instruction in this project. The positive side of this condition remains that students will be familiar with the use of their own hardware. The negative aspect of this requirement is that not all students will have the mobile technology required to run the software at its recommended hardware specifications. It is assumed that students will have a mixed response toward their augmented or virtual reality experience based on the hardware at their disposal. Given the course enrolment totals, a school supplied hardware solution remains impossible but will be investigated in future research.

CHAPTER II

LITERATURE REVIEW

Introduction

The purpose of this project is to generate mixed reality media to be utilized in a first-year undergraduate engineering graphics communication course, in an effort to help engage students in the material as well as to enhance their spatial visualization skills. The literature review will explore the significance that augmented and virtual reality may play in education, through the examination of previous research, preceding methodologies, and their collective implications. An investigation into this three-dimensional media's potential role in engineering graphics courses were investigated. Additional studies were conducted for use in future research concerning the potential impact that these technologies had in previous studies involving the participating students' impact on motivation, and the influence that these augmented and virtual reality files have had on students' spatial skills development. Based on the information collected, the deliverables for the project were established, along with the most commonly utilized standardized metrics and assessment tools be used to assess MECH 100 students' progress with this project's mixed reality media.

Background

Mixed Reality Definition

This project focuses on the use of *mixed reality* (MR) media, which is considered to be a subset of *virtual reality* (VR) technologies that constitute a merged real and synthetic virtual world somewhere in the "*virtuality continuum*," that connects the real with completely virtual ones (Milgram & Kishino, 1994). This continuum described by Milgram (as shown in Figure 1) illustrates the span from completely real environments on the left to virtual environments on the opposing side. The real environments side, at its extremum, consists of only real objects while the virtual environment side would consist of an entirely graphical simulation of reality. Mixed reality environments lay in the grey space between the real and virtual worlds, and may include varying levels of complexity and stimuli.

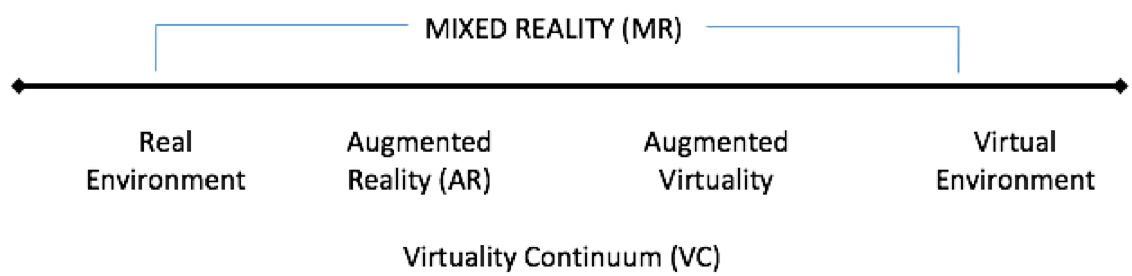

Figure 1. An example of Milgram's Virtuality Continuum.

Source: Adapted from Milgram, P., & Kishino, F. (1994, December). A taxonomy of mixed reality visual displays. *IEICE TRANSACTIONS on Information and Systems*, *E77-D*(12) 1321-1329.

The conventional interpretation of *Virtual Reality* (VR) involves one where the user is totally immersed in, and able to act upon a synthetic environment (Milgram & Kishino, 1994). *Augmented Reality* (AR) remains to be a real world environment augmented by means of computer generated content tied to specific locations and/ or activities (Yuen & Johnson, 2011). As the proliferation of mixed reality technology continues, its use is being investigated for ventures outside of the realm of entertainment. In recent years, academics and educators have been evaluating mixed reality's role in enhancing instruction and increasing student motivation (Lee, Wong & Fung, 2010).

Definition of VR

Researchers have grappled with an accurate way to define virtual environments. The concepts are abstract at best and complications arise when an individual contemplates what does it truly mean to provide a user with a virtual reality experience? Some researchers believe that this virtual reality classification is best described by the hardware that is utilized to deliver the experience, and the amount of realism they provide (Milgram & Kishino, 1994). Others emphasize that researchers must consider the user's perception of *presence* that an individual may feel when experiencing a vivid virtual environment (Steuer, 1992). For the purposes of this paper, the classification of virtual reality remains in terms of a human-centered experience involving a user's presence, rather than a technologically based hardware classification. The use of a cardboard hardware set-up is commonly referred to as a virtual reality experience in main-stream media and the PSM project references this association in the classification of the virtual reality environment that was developed for instructional use in the course of this project.

These taxonomies describing what constitutes a virtual environment were established some time ago, during the rise of virtual reality in the early to mid 90's. These taxonomies developed a means for researchers to present established and accurate classifications so that they could allow for more focused conversations, research, and data collection on the topic virtual reality. Even with the existing taxonomies, information, and research, there is still much discussion involving a definite answer to what constitutes a virtual reality experience. Regardless of these differences, several of the more notable taxonomies in the literature that are relevant to this discussion are summarized in the following paragraphs.

In 1991, Naimark proposed a taxonomy to categorize different techniques to create an imitation of a real visual experience. This lead to the definition of real-space imaging which includes mono-scopic imaging, stereoscopic imaging, muti-scopic imaging, panoramic, surrogate travel, and real-time imaging (Naimark, 1991a,b).

In 1992, Sheridan was the researcher who proposed the measure of a user's presence that depended on three specific criteria: the extent of the sensory information provided to the user, the control of relation of sensors to the environment, and the user's ability to manipulate or modify the physical environment. These tasks were assessed according to the task difficulty and the degree of automation (Sheridan, 1992).

Also in 1992, Zelzer proposed a three-dimensional taxonomy of graphical simulation systems. Zelzer's classification incorporated the human element with the technological hardware components. The taxonomy was based on autonomy, interaction, and presence (Zelzer, 1992).

Robinett in 1992 proposed an extensive taxonomy that laid the foundation for a *synthetic experience* or technologically mediated interactions that dealt exclusively with head-mounted displays (HMDs). This classification consisted of nine elements: causality, model source, time, space, superposition, display type, sensor type, action measure type, and actuator type (Robinett, 1992).

These taxonomies of the early to mid-1990's were influential in establishing the foundation of early virtual reality research. Over time, these concepts are still valid in the classification of a user's virtual reality experience, but much has changed with the development of new sophisticated and more compact virtual reality related technologies. For example, virtual reality experiences in the 1990's required expensive HMDs, and haptic interfaces consisting of bulky and cumbersome gloves. To provide a user with an immersive experience, more than likely the use of this technology kept them grounded in reality. Even with the progression of virtual reality hardware technologies, where a user experiences complete presence in a virtual environment and is exposed to virtual optics, sounds, haptic sensations, even smells, users are still subject to the real world laws of nature like gravity. Taking these laws into consideration, can a virtual environment provide a truly realistic experience? Chances are, that a user's perception of presence will be dictated by the incorporation of earthly restraints like gravity to provide realism in a hypothetical virtual world. Since some components of what makes up our perception of reality may be impossible to ignore with the current state of virtual reality technology, Sheridan's taxonomy on virtual reality involving presence remains appealing and relevant to this discussion.

<u>Presence and Telepresence</u>

The key to a synthetic virtual reality experience remains the human concept of presence. *Presence* is described as the sense of being in an environment (Milgram & Kishino, 1994). This concept of presence is easy enough to understand but has become clouded over time. As technology continues to advance, almost unknown to the majority of its users, the incorporation of mixed reality media is becoming ever more present in everyday applications. Most notably, with the proliferation of the smart-phone, individuals can get instant information regarding their surroundings in real time. Compared to life several years ago, our everyday experience with technology has already significantly augmented our perspective of reality. In essence, many people may not be aware, but are already experiencing a form of augmented reality in everyday life on the lower left end of Milgram's virtuality continuum, by remaining connected to their phones, tablets, or watches.

Presence takes on a new meaning with virtual reality. Virtual reality forces the user to perceive two separate environments simultaneously (Steuer, 1992). Virtual reality as described by Sherman and Craig (2002) is rationalized as anthropocentric in nature by "a medium composed of interactive computer simulations that sense the participant's position and actions and replace or augment the feedback to one or more senses, giving the feeling of being mentally immersed or present in the simulation". Virtual reality is experienced through a multitude of input and output devices, which allows for a bidirectional flow of information between a user and a virtual computer generated (Häfner, Häfner, & Ovtcharova, 2103). This viewpoint explains how a stereoscopic presentation is provided to the viewer, which consists of computer generated objects that are true to size and shape. Most commonly, HMD hardware and can track the user via the associated sensory inputs depending on the hardware utilized. This taxonomy blends the human-centered element of presence with the technological requirements of virtual reality hardware.

Humankind continues to carry out their lives in a three-dimensional environment, but due to the limits of available technology, they are used to communicating with the outside world in two-dimensional realms. Telephones, text messaging, and email remain the staple of current communication practices. These approaches, although effective, filter out much of the complexity of whom we really are, specifically relating to non-verbal communication (Hughes, 2012). This lack of depth excludes voice inflection, body posture, and other common non-verbal socially accepted communication cues. Only after understanding the limitations of current technologies, can we come to understand that these legacy tools lack the humanistic conceptions of space, location, size, and physical presence (Hughes, 2012). *Telepresence* may be a more accurate description of this state of virtual existence, which is the extent an individual feels present in the mediated environment. *Telepresence* is the experience of presence in an environment by employing a communication medium (Hughes, 2012). This definition allows for us to associate a natural perception of an environment, vs. the mediated perception a user experiences being subject to two simultaneous environments. This realization allows us to understand mixed reality's role in future technologies, and will infiltrate all levels of human interactions up to and including education.

Virtual reality provides a computer generated reality, which has the potential to call into question, what does it mean to "be somewhere." Students engaged in a virtual environment can be physically present in a lecture hall, but the user can be consciously present in another time, space, or realm. With virtual reality someone can be sitting right in front of you with a headset on, and you will have to ask the user, "where are you?" Very shortly, mixed reality will become the only reality.

What is Real, What is Virtual

The complexity associated with providing a user with a virtual environment involves the differentiation between what the researcher defines as what is real and what is virtual. This notion may provide to be a critical one since virtual reality can rely on both as its foundation. This complication becomes evident with respect to the concept of human presence, specifically how a human may get the impression that an artificial environment can be real. According to Milgram (1994), real objects are any objects that have an actual objective existence, while virtual objects are objects that exist in essence or effect but not formally or actually. These classifications are elementary, but in the case of image quality and high definition, a human user may not be able to truly decipher the difference.

To discriminate what is real and what is virtual, researchers must discuss three key elements relevant to these tangible and virtual worlds. These topics include: how much a user knows about the world being reproduced, how real is the display, and how present is the user within this world? These questions will help to differentiate virtual experiences in Milgram's mixed reality continuum.

Augmented Reality Definition

Like virtual reality, scholars have had a difficult time deciding on an accurate description of augmented reality. As with the dilemma expressed in virtual reality, this is mainly due to the inclusion or exclusion of particular technologies in the definition. Augmented reality is not limited by a certain type of technology. Augmented reality is experienced through a broad range of technologies like hand-held devices, desktop computers, head-mounted displays, as well as many others. Augmented reality exploits the affordances of the real world by providing additional contextual information that augments learners' experience of reality (Squire & Klopfer, 2007). As a result, augmented reality differs from virtual reality in that it supplements reality, compared to attempting to replace it.

Augmented reality combines a virtual world with the real world, which augments or supplements the user with a wide range of possible interactions. The level of the supplemental information or interactions can range on the mixed reality continuum, but will always remain connected to the real world. Examples of augmented reality interfaces include smart-phone applications, interactive windshield mounted displays for cars and the cutting edge technology in a fighter pilot's helmet. Augmented reality augments the users' physical environment through a collaboration of virtual and real environments (Azuma, 1997).

Like virtual reality, augmented reality requires several hardware and software components to provide the environment to the user. The hardware component involves a central unit with the capacity to process and run an augmented reality software package. Augmented reality is not confined to a desktop computer due to the current state advancements in a mobile platform's processing power. Augmented reality software is now able to be run on mobile devices like smart phones and tablets. To run augmented reality software, these devices also require a connected camera to register an augmented reality marker. The devices use these markers to anchor the augmented reality image to the real world by superimposing the virtual image onto the marker. Users are then capable of interacting with the marker, while the software and device register the corresponding movements with the tracking camera. An example of an AR environment depicting an exploded view of a gear box assembly used in MECH 100 Lecture is shown in Figure 2. In this picture, students in MECH 100 are shown a Gear Box assembly in an exploded state to aid in the creation of their own drawings.

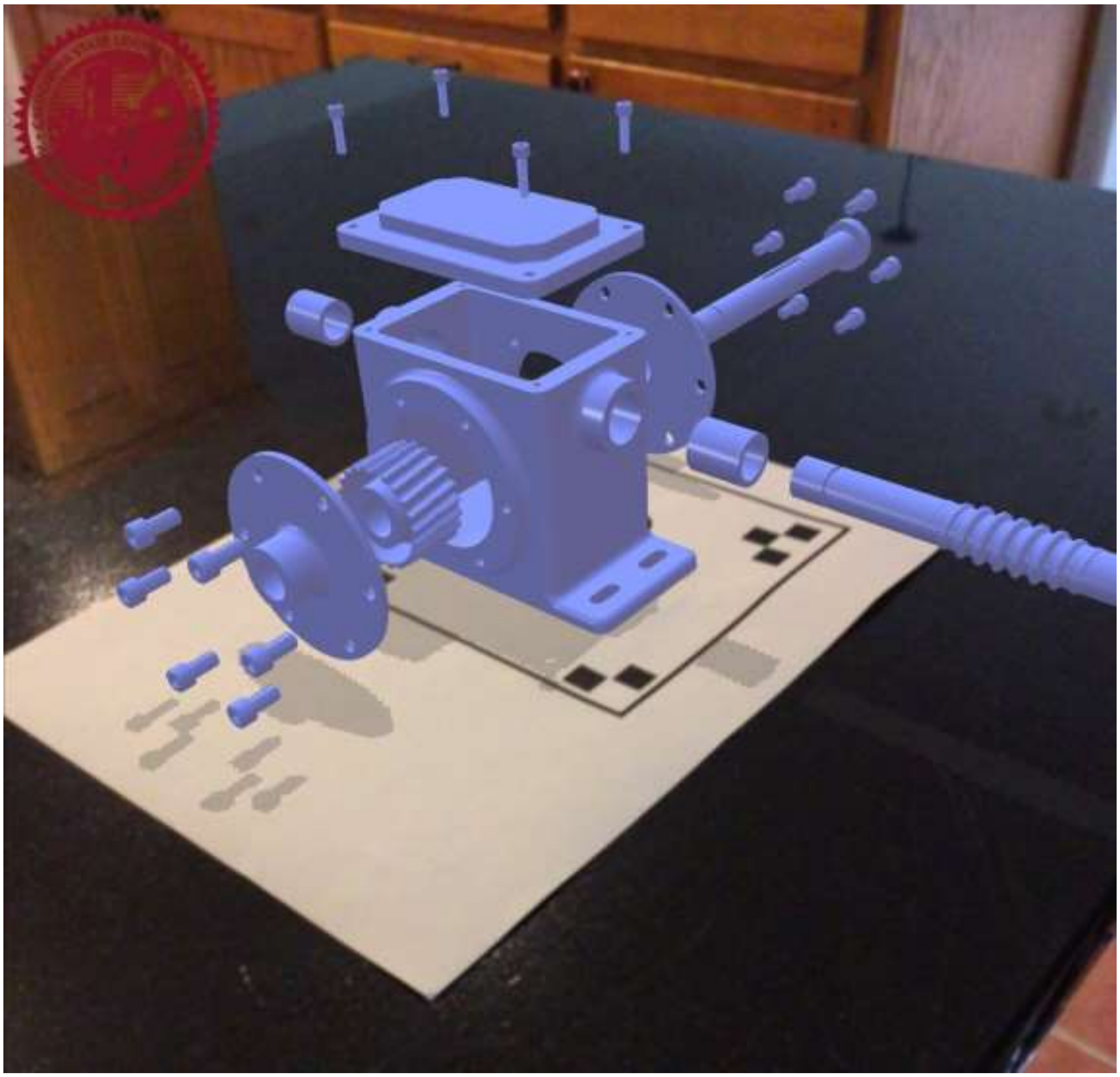

Figure 2. Augmented reality environment with Augment® software depicting an exploded view of a gear box assembly from Alejandro Reyes' *Beginner's Guide to SolidWorks® 2015.*

Source: PSM project material by Charles J. Pooler.

One technology that is gaining traction in both virtual and augmented reality is the use of HMDs. What was previously accomplished with cumbersome hardware ion the 90's can now be accomplished via smart-phones armed with forward facing cameras, powerful mobile processors, and extremely sensitive accelerometers. Because of these advancements in technology, and the mass production of the resulting hardware the costs associated with HMDs have been steadily dropping. In the 90s, presenting broad and complex environments with reduced latency required large sophisticated hardware at a significant cost to consumers. These devices lacked these refresh rates and the adequate frames per second that create smooth transitions in virtual worlds to replicate a realistic impression. Head-mounted devices have evolved to translate head movement, camera movement, and are proving to be an effective way of providing an experience adequate for displaying models in an engineering graphics course. HMDs allow students to render an environment relative the user's perspective (Hilfert & Konig, 2016). The ability for the HMD to register moments with the head and body and then to translate that to an avatar within the virtual environment are akin to the concepts of augmented reality, but lack the ability to blend the environment with the real world.

Based on the taxonomies and classifications presented in the literature review, several similarities are evident between augmented and virtual reality. Both augmented and virtual reality incorporate computer generated graphics, and draw from a central processing device that presents this information to the user via some variation of an interface. Both technologies provide the user with an interactive or immersive experience while providing information sensitivity (Yuen & Johnson, 2011). Based on these conclusions, much of what is discussed in virtual reality research may apply to augmented reality, and visa verse. For this reason, the inclusion of both augmented and virtual reality studies can be utilized in the discussion of this project.

Due to the similarities of augmented and virtual reality, their potential uses in the college classroom were researched for the purposes of this project. Both augmented and virtual reality are gaining traction in education due to their ability to create an interaction between the student and a computer generated virtual world; that enhances student knowledge by learning through an experience or activity (Roussou, Oliver, & Slater, 2006). Although virtual reality requires additional work to develop and implement, its benefits for instruction cannot be ignored. For these reasons, the deliverables for this project were to include both augmented and virtual formats for incorporation into an engineering graphics course at CSUC. The project should be used as an opportUnity to create augmented, and cost effective virtual learning environments for students. Based on these criteria, the virtual hardware elements were specked to meet strict cost requirements that a typical engineering student would have to absorb.

In some cases, mixed reality media implementation is easier said than done. This virtual environment is administered by the teacher, in a laboratory that can support the associated curriculum. Although mixed reality is finding its way into more and more classrooms, without trained instructors and the right infrastructure, the pursuit of mixed reality in academia is futile. To successfully integrate mixed reality in the classroom, the proposed class must have instructors with the knowledge and skill required to implement the associated environments, and there must be a course where the application of mixed reality aligns with the student learning outcomes of the class.

Virtual Engineering

Virtual engineering is defined as a process which integrates geometric models and related engineering tools like analysis, simulation, optimization, and decision making tools within a computer-generated environment that facilitates multidisciplinary collaborative product development (Häfner et al., 2013). Engineering students emerging from various engineering colleges can expect to find themselves working in interdisciplinary teams and working with advanced technologies in today's constantly evolving industry. Today, there is a broad usage of virtual reality technology in industry, which establishes a need for universities to offer mixed reality courses due to this growing segment of the job market. In 2003 one-hundred and forty-eight Universities (3%) and in 2008 two-hundred and seventy-three Universities offered courses in virtual reality (Häfner et al., 2013). An important aspect of this virtual reality education must include both practical hard skills and the discussed soft skills, as well as methods that enhance virtual engineering like augmented and virtual reality from introductory engineering graphics courses. Virtual reality courses are on the rise, but the majority of these introductory engineering computer graphics courses still exclude the incorporation mixed reality.

Technology in Engineering Graphics

One of the most promising applications of mixed reality in education remains its application to engineering graphics. Engineering graphics courses are designed to develop a student's ability to communicate and convey key concepts to another quickly and accurately without the use of words (Lieu & Sorby, 2016). These courses typically entail education that pertains to industry standards, elements of hand sketching, creativity and design, the application of a professional *computer aided drafting* (CAD) software package, and using this software to develop the associated highly detailed working drawings. To create a set of detailed drawings, a student is expected to learn strict industry standards and protocol that range from geometric dimensioning and tolerancing standards to visualizing rotations of geometric shapes about their axes. These lessons require a great deal of attention as well as the discipline to completely understand, yet let alone, master. It remains a well-known fact that due to the complex set of skills vital to succeed in engineering courses, like these in engineering graphics, many students withdrawal, fail, or give up believing that they do not fit a specific mold. To succeed a student must develop the associated "hard skills" like a thorough understanding of physics and math, as well as "soft skills" like interpersonal relations and spatial and visualization skills.

Based on the research conducted in the literature review, the development of these spatial skills remains a major factor in student success with respect to engineering graphics courses. These skills allow students to visualize an object, and manipulate, rotate, or twist it in their mind. Research has shown a correlation between a student's spatial visualization acuity and their ability to master CAD software packages (Norman, 1994). In longer studies, the development of these skills have been related to superior calculus course grades (Sorby, Veurink, & Dulaney, 2013).

Practicing engineers are routinely asked to create 3-D geometry in a CAD software package. In doing so, they are also required to visualize in their mind a part's form and function within an overall assembly. According to studies conducted, like that of the Johnson O'Connor Research Foundation in 2005, show that practicing engineers have mastered spatial visualization skills. Through the research conducted in this project, it has also been shown that one of the most widely accepted, and accurate ways to assess these student's spatial abilities is through the mental rotations component of the *Purdue Spatial Visualization Rotations Test* (PSVT: R). As discussed, this test has proven to be the most pertinent means of projecting engineering graphics student success out of 11 variables tested (Sorby et al., 2013). For comparison, the PSVT: R link to engineering graphics student success was stronger than the math, verbal, science, and composite component scores of the ACT (Gimmestad, 1989). These spatial skills have been widely researched, and have been shown that students with advanced spatial skills tend also to be capable of higher level thinking, reasoning and creative processes (Sorby et al., 2013).

The Johnson O'Connor Research Foundation study, surveyed 32,000 individuals, approximately equal parts women and men, and found that both students and actively practicing engineers had highly developed spatial visualization skills compared to other professions (Johnson, 2005). The Johnson discussed the link between successful practicing engineers in industry and developed spatial visualization skills. The Johnson study was also quick to point out the fact that it was impossible for them to ascertain whether or not these male and female participants had highly developed spatial skills and gravitated to the engineering discipline, or if these individuals developed these skills over time.

<u>Gender Gap</u>

Research provided by the Johnson O'Connor study elaborate on another unfortunate truth. In an ideal world, the engineering profession is made up of equal parts male and female, but that is simply not the case. In 2003, 11% of engineers in the workforce were women (Liana, 2013). These statistics hold true to undergraduate engineering education as well. STEM fields remain male dominated, with engineering disciplines remaining one of the most dominated. In 2005, 20% of B.S. degrees were awarded to women (Sorby et al., 2013). More current information from the 2011 Census shows an upward trend, with the composition of women in the engineering field at 13% compared to information provided in 2003 (Beede et al., 2011).

Spatial visualization skills, specifically mental rotations, remain one of the most investigated and documented male dominated cognitive gender differences (Voyer, Voyer, & Bryden, 1995). In a study by Lippa, Collaer, & Peters (2010), 90,000 women and 111,000 men from 53 nations were given a mental rotations test, in which male subjects averaged higher scores than the women participants. One of the more interesting conclusions drawn involved a greater gender inequality in nations with higher economic development as assessed with life expectancy and income. Developed countries who have adopted a greater level of technological society were the ones that experienced the widest gender inequality gaps concerning spatial skills (Sorby, et al., 2013).

Research that illuminates gender disparity in spatial visualization skills may portray a more discouraging truth prevalent in the engineering field. Regardless of previous conclusions drawn in research, it is important to note that spatial visualization skills vary from person to person. Some individuals may have advanced visualization skills that are innate or developed, and others may not. The bottom line remains that spatial visualization skills are like any other set of skills. These skills can be developed over time with the right tools and the right learning environment. For the purposes of this project, it is assumed that the use of innovative teaching tools like augmented and virtual reality media can play a pivotal role in spatial skills development to a diverse group of undergraduate engineering students regardless of gender, age, and race. This advancement in spatial skills will be enhanced by providing the student with a new three-dimensional interactive perspective not traditionally available with more traditional two-dimensional media.

Given the link between student success and these soft skills, spatial visualization training and development must be an essential component of undergraduate engineering graphics courses. It is possible that following a spatial training regimen in an engineering graphics that these students with less developed spatial abilities will succeed in school to eventually graduate and enter the work-force as successful practicing engineers. The application of the spatial visualization training in an undergraduate engineering graphics course should emphasize elements like mental rotations, and incorporate new methods of technological advancements to stay true to industry demands while motivating students to stay engaged and ultimately graduate. The use of mixed reality in the classroom can play a role in spatial visualization training while motivating students by engaging them in virtual environments that they can control, interact with, and collaboratively work to solve complex engineering related problems using a hands-on approach.

Examples of Mixed reality Media in Education

In 2014, Sampaio and Martins used a virtual reality application to aid in the visualization of building a bridge using two separate construction methods. The intended goal of the simulation was to help show students additional perspectives to develop a deeper understanding of the process. Virtual reality was an obvious choice because of the ability to place a student on the job site in a virtual environment. This would not be possible in reality, due to strict safety protocols associated with hazards related to the real job site.

In 2014 Merchant, Goetz, Cifuentes, Keeney-Kennicutt & Davis explored the literature on virtual reality-centered learning concerning learning outcomes in an educational setting. The authors concluded that in their assessment that "virtual reality based instruction is an effective means to enhance learning outcomes" (Merchant et al., 2014). As previously mentioned, one of the reasons that virtual reality has not been widely adopted is because VR environments were required to be married to a desktop computer which inhibits user immersion. Regardless of the need to be connected to a desktop computer, it was concluded that the virtual reality based instruction was still advantageous over the equivocal traditional learning environment, especially concerning its link to student engagement (Merchant et al., 2014).

Motivation

Mixed reality can place students in virtual environments not possible, compared to a traditional learning environment (Allison & Hodges, 2000). By providing an accurate and diverse virtual environment that a student can interact with, students can personalize their experiences, and internalize the content presented through first person interactions (Di Serio, Di Serio, Ibáñez, & Kloos, 2012). This inclusion allows students to maintain a higher level of attention and interest in the lesson content (Allison & Hodges, 2000). The use of augmented reality, in a means that combined both virtual and real environments, was found to be both interesting and motivating for students (Lee et al., 2010).

Augmented reality's ability to blend synthesized and real worlds can create complex but compelling learning environments for students. In 2007, Serdar, Stevens, Ses, Esche, & Chassapis concluded that the use of augmented reality in an engineering graphics course led to increased student interest and awareness in the lessons provided (Serdar, 2013). In a case concerning a group of kindergarten students, the incorporation of augmented reality had such a strong impact on motivation, that students refused to quit a game presented until the virtual task was complete (Campos, Pessanha & Jorge, 2011).

<u>Retention</u>

Virtual environments can aid in knowledge acquisition. Brelsford (1993) conducted a study utilizing virtual reality in a simulator to help physics students gain a better understanding of gravity and motion. Students were able to manipulate a pendulum, and three balls of varying mass. These students were able to influence factors like gravity, air drag, friction, and several other variables and were told to perform these experiments for one hour. A control group was presented with a lecture of the same material for an hour. After four weeks, students were administered a surprise exam over the materials covered in the pendulum lesson. Students who had used the virtual lab showed better retention then the control groups whom participated in the lecture (Brelsford, 1993).

<u>Pedagogy</u>

Mixed reality can expose students to a wide range of viewpoints through virtual environments provided by the instructor in the teaching process. From a pedagogical perspective, constructivist theorists argue the case; where the more views presented to the student the more that they learn, and retain what they learn (Allison and Hodges, 2000).

The utilization of multimedia in learning has gone beyond video and graphics, and is now growing to include mixed reality in the form of *virtual reality learning environments* (VRLEs). This transition from a web-based media approach provides a more immersive, interactive, and involved virtual environment for students. By utilizing a virtual environment, an instructor can simulate the real world through the application of computer-generated three-dimensional models. The question remains whether or not the instructor can create good pedagogy practices. The use of VRLEs identifies with a constructivist learning theory as the pedagogical tool. The use of mixed realty media is promising but must begin with effective pedagogy.

The constructivist theory involves students taking an active role in their learning. This theory assumes that students will learn the associated material by connecting the provided lessons and materials to generate their own new knowledge. According to constructivist theorists like Dewey (1916), Knowledge is based on an active experience, and the educator’s role in the process was to fashion this information which seamlessly combined with the real world to better understand their surroundings in an effort to improve their reasoning processes. The learner learns how to solve problems through this process of discovery. These discoveries build upon meaningful individual experiences.

Above all for engineers, problem solving remains a vital trait associated with the job. Constructivist theorists also believe in creating environments that enhance *problem-based learning* (PBL). Mixed reality environments can allow students the ability to visualize and solve computer generated problems in a virtual environment. The instructor can develop an immersive experience that can prompt exploration to solve a problem, which encourages the student to do so by way of discovery in the VRLE. Due to the dexterity of the environments, augmented and virtual reality deserves recognition as an innovative teaching tool. Through intuitive interaction, curiosity and imagination, and the feeling of immersion through a sense of presence, mixed reality media can motivate the student's pursuit of knowledge.

Project Design

Mixed reality can be used to teach a diverse assortment of topics. The use of mixed reality has been shown to be effective in the classroom, but its development requires substantial time and effort to generate and distribute the content. Infusing mixed reality into courses like engineering graphics requires the instructor to use the experience to enhance student learning, and not make it the centerpiece of a student's learning experience (Allison & Hodges, 2000).

For the students to get enough time with the software to help develop their spatial visualization skills, an adequate amount of time is required for treatment with the instructional materials. Studies like Blasko and Holliday-Darr (2010) allowed students to engage with the software for a total of six hours. In another study by Martin-Dorta, Saorín, & Contero (2008), the researchers noted that a quick remedial course in spatial training that consisted of about six to twelve hours can have a significant impact on spatial ability. For mixed realities' successful implementation in an engineering graphics course, the instructor must find an adequate balance of time, while creating assignments that present the lessons in an active mixed reality environment.

Based on the literature review the incorporation of mixed reality environments in the classroom has pertinence, and justifies the proposed project. The effects of augmented and virtual reality were evaluated, analyzed, and grouped into categories that embodied the elements that were most significant. These main topic areas include the use of mixed reality as a means of enhancing spatial visualization skills in undergraduate engineering students, as a means of motivating student engagement in the associated lessons, and to create experiences otherwise impossible in traditional classrooms.

The key element to the design of VR files and the effective VR implementation was researching the transition required to move from CAD to VR. Edwards, Li, & Wang (2015) illustrated how a video game engine could be used to incorporate end-users in the building information modeling (BIM) design process. Through the use of a plug-in for Autodesk Revit® they illustrated the feasibility of a CAD system's ability to communicate with the Unity 3d® game engine. This process enabled collaboration over a networked connection to generate an interactive, three-dimensional environment for designers. This study opened the door to the opportunities associated with game engines and CAD software but lacked the virtual reality instructional component and cost effectiveness that remains core to this project.

Chapter Summary

From the literature reviewed for the project, it is evident that there is potential for mixed reality in the classroom. As previously discussed, cost remains a key barrier to entry, therefore, a low-cost solution seems most desirable to distribute to a diverse student population. This VR environment must be accessible, easy to operate, and enhance classroom involvement does not digress from it. Additionally, components must be off the shelf, and able to be used in other applications to allow for the lowest possible cost and allow for additional applications.

CHAPTER III

METHODOLOGY

The project design was structured according to the information uncovered in the literature review, as well as the assessment of the current status of the MECH 100 Engineering Graphics I course at CSUC. The conclusions drawn from the research uncovered in the literature review created the foundation for the outline of this project. After the evaluation of this information, all applicable steps were taken to ensure that the use of augmented and virtual reality would not inhibit instruction, but be applied as an instrument to enhance the students' learning environment.

The incorporation of mixed reality media in the classroom requires an accurate assessment of the currently employed instructional methodology (Núñez, Quirós, Núñez, Carda, & Camahort, 2008). For the project to successfully integrate mixed reality media in the classroom, the content must align with student learning outcomes associated with the class. The resulting material needs to address the fundamental topics in the course (Chen et al., 2011) and done in a manner where the use of these models adequately utilizes augmented and virtual reality in a way that adds understanding to the course content. After examining the potential strengths associated with mixed reality in the classroom, the application and use of this technology must be applied to specific content areas that have the potential to elicit the greatest effect on student learning.

When planning the deliverables for the project, there were several factors that the researcher had to take into consideration. One key element was that the current course lecture would not impact the use of mixed reality technology. For students to fully utilize and experience the benefits of this technology, the homework was selected as the treatment conduit. The reasoning for this decision was to allow students to take as much time as necessary outside of the once a week hour-long lecture to complete the augmented and virtual reality assignments at their leisure, and on their own time.

Designing the mixed reality components must take into consideration the learning curve with using the associated software. Studies conducted by some researchers expressed the need to start with less complex models in the early stages of implementation while expanding to more complex as student users develop more confidence with the technology (Shelton & Hedley, 2002). In other cases, augmented reality files were created and given to CAD students to better visualize the desired end result of their assignment CAD assignments. After reviewing these previous studies, models were created to aid in understanding the lecture topics, to be included in the completion of the homework. From the information collected in the literature review, CAD models were created that progressed in difficulty over the semester.

Augmented Reality Intervention

Augmented reality software is becoming more prevalent, as its potential uses are being explored in a multitude of ways, in an assortment of industries and applications. The main technological requirements for the project required the software to be easy to use for students and instructors, as well as to be inexpensive for a diverse student population. If either of these were not met, it was assumed that student users would choose to opt out of using the associated augmented reality software. For these reasons, research was conducted as to what applicable augmented reality software packages were available on the market, to be used in an engineering graphics course.

Another requirement of the selected software was the need for it to allow easy transition from a virtual computer generated CAD solid model, to the resulting augmented reality file. At CSUC, SolidWorks® is the adopted CAD software package of the Department of Mechanical and Mechatronic Engineering and Sustainable Manufacturing. SolidWorks® allows the students to create complex geometric figures using a Windows® based operating system and presents this to the user via a main viewing window. An example of the SolidWorks® user interface is shown in Figure 3. The figure is showing an assembly of a turbofan engine that was created by the researcher in a previous project. The augmented reality software had to be able to receive SolidWorks® compatible file types and easily convert them to augmented reality files.

SolidWorks® has been experimenting with the use of augmented reality, and has launched their version of an augmented reality environment for IOS and Android devices in their eDrawings® applications. The use of this augmented reality software package was an ideal solution as far as the ability to send, receive, and create augmented reality files from SolidWorks®. One drawback, although minor, to formally adopting the eDrawings® software application was that there was a cost associated with downloading the application. This price was competitive at $1.99 but was a factor in the selection of the adopted course software. Additionally, the augmented reality option was only initially

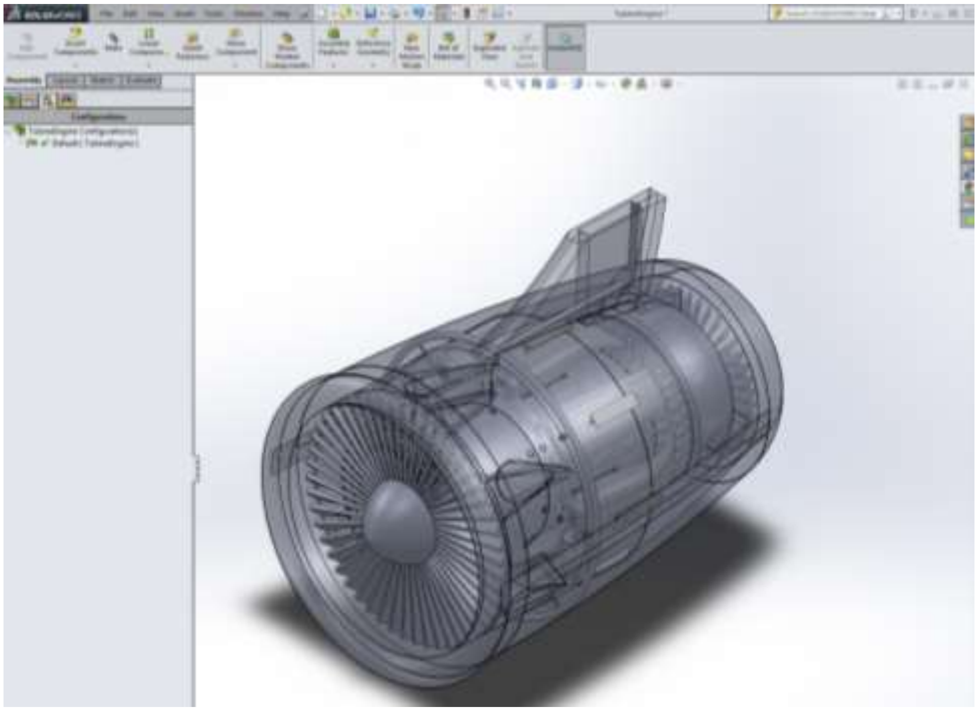

Figure 3. SolidWorks® assembly model example.

Source: Personal works of Charles J. Pooler.

available on IOS devices, and not available for Android® users until version 3.0.1 was released.

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In addition to the cost requirement, there was an issue with the secondary condition with respect to ease of use. Although the eDrawings® software application is elegant in form and function, in order to apply it in an engineering graphics course of close to 100 students required the coordination of pushing the related augmented reality files to the students via email or online learning platforms like Blackboard®. The added step would require the students to not only download the and pay for the SolidWorks® eDrawings® application but also to navigate to the designated course communication medium in order to download and open the part for viewing. Based on the project software selection criteria, SolidWorks® eDrawings® was not selected for adoption.

The other software solution that was uncovered in the literature review was an augmented software package called Augment®. Augment® is an augmented reality application for both IOS and Android® devices, and is available free for student use. To access the free Augment® content, an instructor was required to create an account and register it as educational in nature. After referencing the instructor's credentials, the representatives at Augment® would allocate a singular account that was set up to handle an entire class. Having a singular account made this option ideal with respect of ease of use from the standpoint of the intended student user. A student was not required to set up an account, and only had to reference one single location that was administered via the course instructor. After meeting the cost and ease of use requirements, it was discovered that Augment® software was able to accept specific SolidWorks® file types to convert into the associated augmented reality files for the assigned homework. For these reasons the Augment® software was selected for use in MECH 100 Lecture.

After selecting the augmented reality software, it was necessary for the researcher to develop and choose the interface that the students would use while evaluating the augmented reality files. The most intuitive interface for the developed homework was through the use of a student's personal handheld smartphone or tablet display. HMDs are an option for augmented reality file viewing, but the homework required the ability to create the right blend of virtual and real environments to maximize student learning and interest. These devices allowed students to investigate numerous perspectives through a device that they were already familiar with handling. This solution made sense based on the literature review regarding ease of use, the incorporation of multiple perspectives to enhance learning, while ensuring an adequate scene of user presence to stay focused on the presented lesson.

The last step before creating the CAD solid models, was the incorporation of the augmented reality marker. These markers are readily available both through Augment®, as well as other online providers free of charge. These markers were downloaded by the researcher, scanned, and linked to the associated augmented reality files for the students to manipulate during their homework exercises. A sample AR code that was created by the researcher for use in MECH 100 is shown in Figure 4 for reference.

For added simplicity, the researcher attached these markers to the developed homework for the students. To complete the homework, a student logged on to the online learning platform Blackboard®, navigated to the MECH 100 Lecture course, and

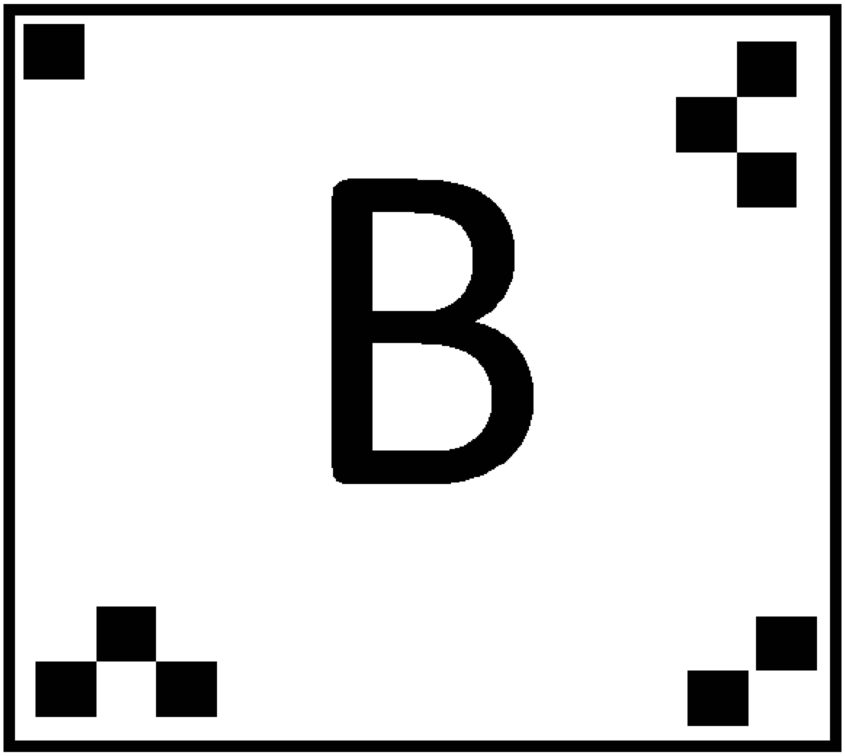

Figure 4. A sample augmented reality marker for an exploded view of a gearbox reduction assembly in MECH 100.

Source: Charles J Pooler personal project.

downloaded/ printed the homework. Students were required to download the Augment® application on their smart-phone or device, and upon opening the application, merely needed to point their camera at the AR marker placed on the associated homework assignment to scan it, view it, and interact with the augmented reality file.

The creation of these augmented reality files consisted of several phases, to navigate from concept to finished product. One of the more difficult steps in the process was developing a model, and an associated exercise that would maximize student learning in a way that was intuitive and easy to understand. Conceptualization of each model required a deep understanding of the intended course topics to create an adequate solid model that did a worthy job representing the corresponding lesson. If the instructor failed to understand the complexity of the importance of this process, the incorporation of mixed reality may be inhibited, not due to the technology, but as a result of the exercise itself. For this reason, more time was spent investigating the potential lessons applicable for mixed reality media integration, and the development of the corresponding model files took longer than was anticipated. Multiple revisions and exercises were developed before settling on several examples that included the right blend for students.

After conceptualization, SolidWorks® CAD software was utilized to create the associated files. SolidWorks® CAD software is a parametric modeling software package that allows a user to generate three-dimensional models in a two-dimensional work environment. These files are created systematically, and a record of the associated geometric building blocks are stored internally and referenced to produce the resulting geometry in the main viewing window. Upon the completion of the resulting solid model, the user must save the file in a compatible file type for the Augment® software application. SolidWorks® has three standard file type configurations that differentiate parts, assemblies, and drawings. It is necessary for the user to save the file as another file extension to be used in Augment®. The SolidWorks® file option that was compatible with Augment® is called a stereolithography file format, or .stl. Stls are a commonly utilized file type in rapid prototyping and are characteristic of the kinds of engineering students who are engaged in rapid prototyping activities. The .stl format files describe only the corresponding surface geometry of the part. The part’s surface is broken into triangulated surfaces using a three-dimensional Cartesian coordinate system, and there is no scale information making the associated units arbitrary. As shown below, Figure 5 shows a SolidWorks® computer generated wheel-hub prior to processing into the .stl file format. After initiating the “save as” process SolidWorks® publishes the resulting .stl as shown in Figure 6 with the surface geometry required for post processing into Meshlab®.

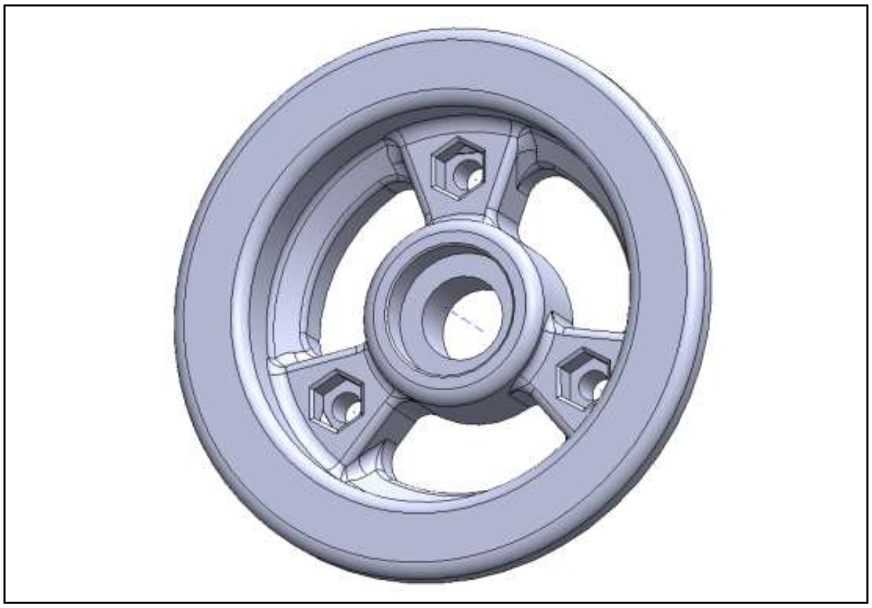

Figure 5. A sample of a SolidWorks® part file in the main viewing window that is ready to be processed into a .stl file format to be entered into the post-processing process in Meshlab®.

Source: Personal works of Charles J. Pooler for the PSM project.

After saving these files as the correct file type, it was necessary to upload the associated files into the Augment® MECH 100 Lecture course page for students to access. Based on the notion that the incorporation of augmented reality in the lecture may not be the best mixed reality environment for the students to experience, the information presented in these studies suggested that at least six hours of treatment was necessary to illicit a positive response to the treatments. By allowing students to utilize the Augment®

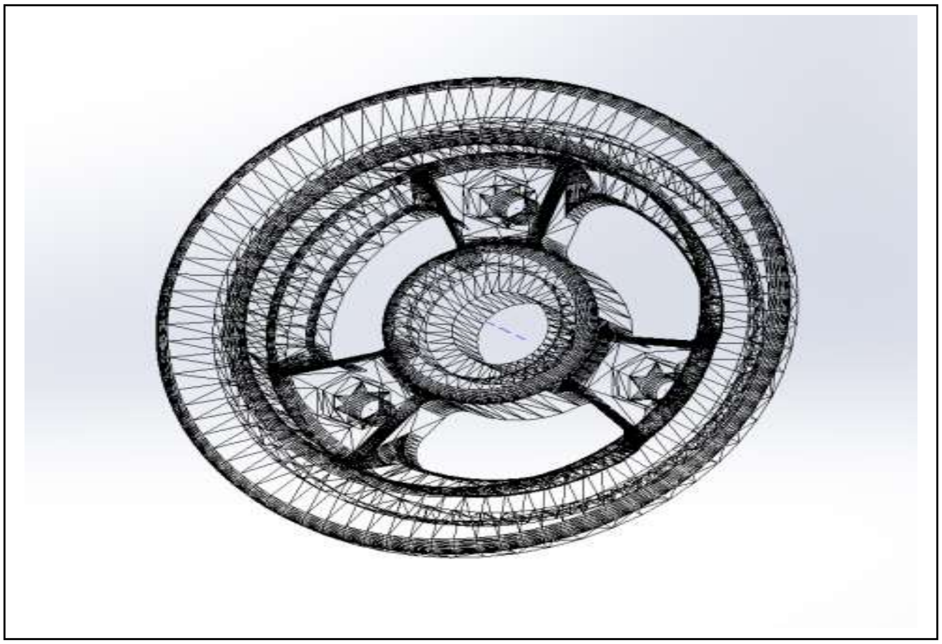

Figure 6. A picture illustrating the tessellation in the conversion to .stl file format. The format creates the surface geometry required to be entered into Meshlab®.

Source: Personal works of Charles J. Pooler for the PSM project.

software at home, it made it possible for the students to experiment with, and fully commit to the mixed reality experience. In the Spring 2016 semester of MECH 100 lecture, there were four homework assignments, three of which included several augmented reality files. This homework was assigned to the students that addressed topics covered in lecture ranging from hand sketching to view selections and geometric dimensioning and tolerancing. A modest assumption was that each homework would take the average student approximately two hours to complete, making the total treatment time six hours for these students. Students were also encouraged to continue to navigate, and become acquainted with the software outside of class assignments.

Implementation of Augmented Reality Media

This project was carried out in Spring of 2016 and is explained in detail in the Table 1. The project was initiated by the administration of the PSVT: R pre-test for all students over Blackboard®, and continued in the forms of homework two through four, and was concluded with the student survey and PSVT: R post test. The project was concluded to coincide with the graduate studies office deadlines in mid April 2016. The project began the second week with the administration of the PSVT: R test to assess the student's baseline mental rotation skills prior to treatment. This test was used as a tool for the students as well as the instructor to gauge each individual student's current spatial visualization skills, and was planned on being administered regardless of the outcome of this project. The results of these tests will be the subject of future research.

Table 1

Project Timeline

Schedule	Date	Description
Week 1	January 25th	First day of scheduled class
Week 3	February 1st	Administration PSVT:R Pre-Test
Week 6	February 29th	Homework 2 Due
Week 11	April 4th	Homework 3 due
Week 12	April 11th	Android .apk VR app distributed to Students
Week 14	April 25	Student Survey Administered
Week 15	May 2nd	Student Survey Administered
Week 16	May 9th	PSVT:R Post-Test Administered

Students were briefed on the PSVT: R Pre-test the second week of instruction, and the test was live during the third week of instruction. During this time frame the students were also instructed on the use of the Augment® software application. After the orientation, the students were assigned the first augmented reality homework assignment, with the understanding that beginning homework two, the Augment® software would be a component of the remaining assignments.

Homework assignment two was the student’s first augmented reality experience using the Augment® application. In this assignment (as shown in Figure 7) students were expected to recreate an object’s geometry in three standard views using third angle projection. By opening and viewing the corresponding model, students could use the augmented reality file as a visual aid to help them with their homework. The students were provided a direct link via hypertext in the assignment, which allowed them to open and view the model. The CSUC emblem was linked to the model as the AR marker, where the 3-dimentional model was projected for their use.

Virtual Reality Intervention

The incorporation of augmented reality into the associated MECH 100 Lecture homework was the first phase of the project. Phase II relied on the creation of an inexpensive HMD for student use to further enhance their understanding of course topics by being present in an instructor created virtual world. The literature review described the recent advancements in virtual reality, as well as the associated barriers to entry. For these reasons, an inexpensive HMD was developed for students to use in an effort to promote a virtual learning environment. The development of this HMD was to align to

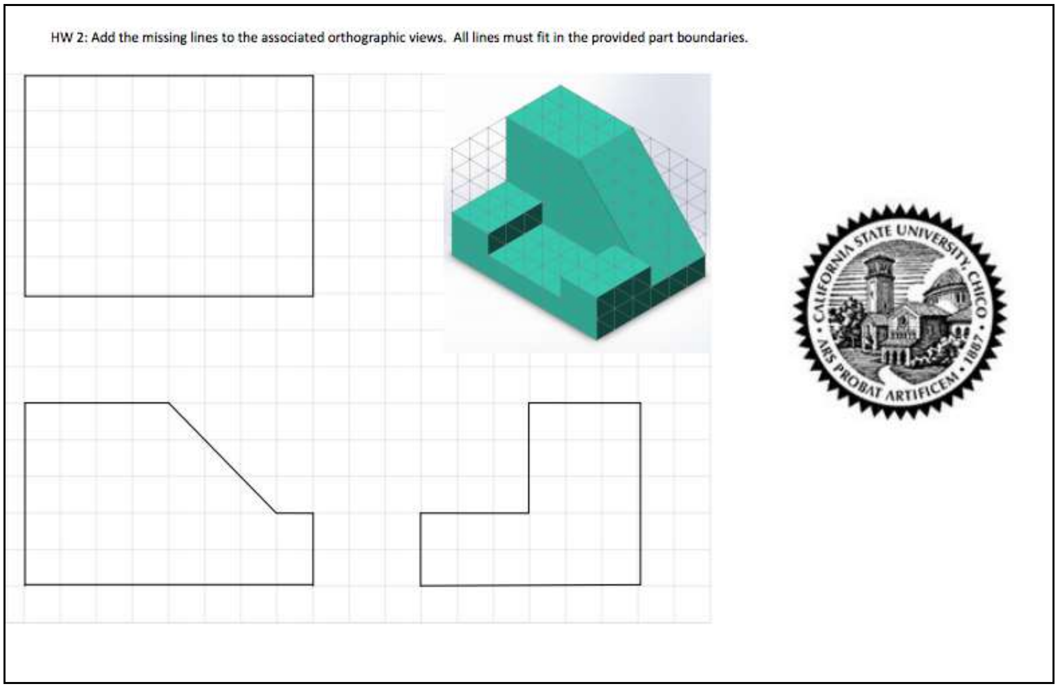

Figure 7. Sample of homework problem from homework 2.

Source: Personal works of Charles J. Pooler.

the criteria discovered in the literature review. The unit must be inexpensive, easy to use, and use off the shelf components to ensure that it could be available to a diverse student population. For these reasons, newer versions of consumer based HMDs like the Oculus Rift® were not selected for use in the project, but if the files were developed correctly, they could be used in both environments.

The HMD developed would utilize a student's currently existing smart-phone, and an inexpensive cardboard VR set-up (sample shown in Figure 8).The hardware would require a software component, that was developed jointly with students and faculty associated with Chico State's *Computer Animation and Game Development* (CAGD)

Figure 8. Image of a cardboard headset.

Source: Photo by Charles J. Pooler.

because of the need for the related CAD files to be imported into a video game engine to be converted into a suitable virtual reality file type.

For the CAD file to be converted into a usable virtual reality file, it became necessary to take the SolidWorks® output file, and transfer this information to a video game engine. The video game engine is capable of generating environments that provide high performance, relating to frames per second, and are capable of creating the most realistic user experience possible. The process of designing a virtual reality file is similar in steps to the creation of an augmented reality file. After generating the engineering solid model in SolidWorks®, the file was exported as a .stl file format to describe only the corresponding surface geometry of the part.

During the literature review, it was uncovered that secondary part processing was commonly utilized when transitioning a CAD file into a virtual reality file. In the conversion process, from CAD file to virtual reality file, there are several types of problems an individual might encounter. These problems range from low performance of larger models, to a lack of realism, inadequate treatment of geometry, the loss of part specific information, and the inability to convert back into a CAD file (Raposo, Corseuil, Wagner, dos Dantos, & Gattass, 2006)

To create a virtual reality file from a CAD file, the CAD file must be prepped before being imported into the game engine. After some discussion with the students and faculty in the CAGD department, a suitable editing software platform was selected. The program that was chosen to import the SolidWorks® .stl part file into for pre-processing is called MeshLab®. MeshLab® is a free, open source, portable, and extensible system for the processing and editing of unstructured 3D triangular meshes like the ones generated by SolidWorks® in the generation of the .stl file (MeshLab, 2016). This system was developed to help edit, clean, and heal the geometry of file types like the .stls generated by SolidWorks®. Figure 9 shows an example of a valve body assembly, consisting of several components saved in the .stl file format, being post processed in the MeshLab® software environment.

After importing the CAD file into MeshLab®, and providing a secondary processing operation to help account for the variations associated with geometric surface modeling concerns, the part was ready to be saved into a compatible file format for the game engine for VR processing. Meshlab® allows users to edit .stl file formats to be saved as other file types that are compatible with multiple game engines. One of the most

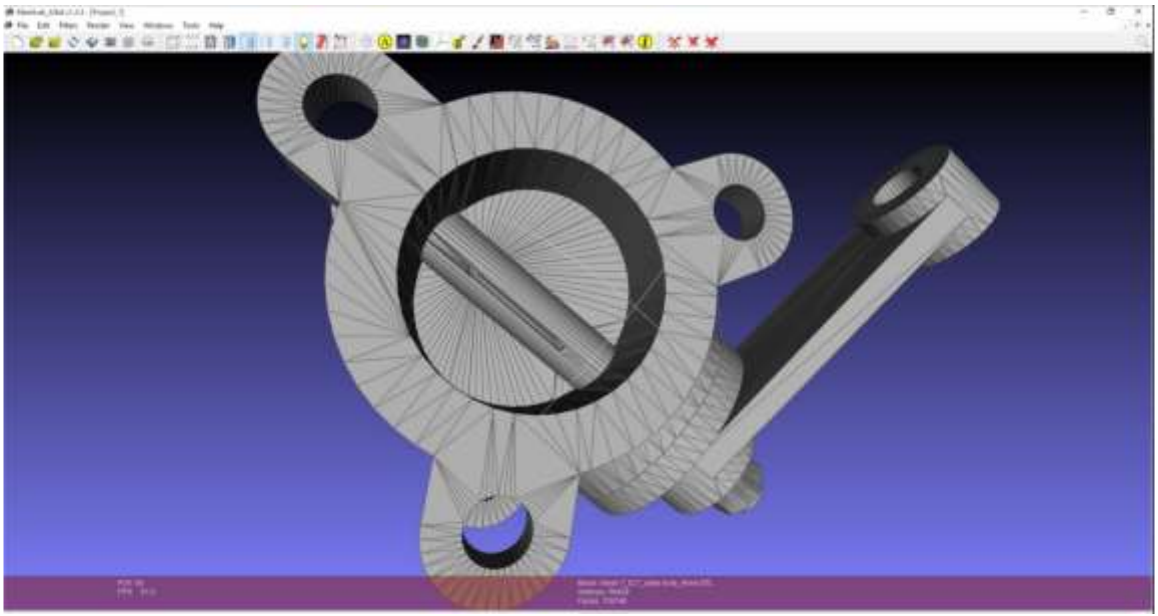

Figure 9. MeshLab interface.

Source: Personal works of Charles J. Pooler.

commonly used three-dimensional file formats used in VR is the *object* or .obj file format. The .obj file format file defines the geometry and other properties for objects that allow the transfer of geometric data between different applications. The data that the .obj files contain involve data that defines the three-dimensional geometry alone. This data includes but is not limited too; information regarding items like the location of each vertex generated in the .stl file, and faces of polygons defined as a list of polygons.

After generating the .obj file in Meshlab®, the researchers were able to import the compatible file into the selected game engine. The game engine selected for this project is called Unity 3D®. Unity 3D® is a cross-platform game engine that was developed by Unity® Technologies, and can be used to produce videogames for PCs, consoles, websites, and mobile devices. Unity® is provided free of charge to student users, and can be used to develop on mobile platforms which were both project requirements.

Unity 3D® has been used by hundreds if not thousands of entities worldwide, and is one of the adopted game engines taught within the CAGD department at CSUC. Given its proven track record, being provided free of cost, and with the ability to develop mobile device applications, made Unity 3D® the ideal choice for the project. The Unity 3D® game engine allowed the researcher and students and faculty in the CAGD department develop an application for an Android device as a proof of concept for the project. The creation of a smart-phone application requires extensive knowledge that pertains to each operating system that the mobile device runs on. Due to the limited duration of the project, only the Android application was pursued as a proof of concept, with the intention that after the project's conclusion the researcher would go on to learn the mechanics of IOS devices.

The Unity® software package allows users to import their .obj file formats into "scenes" which allow the developer the ability to generate specific environments per their specifications. In Figure 10, the Unity 3D® game engine main display is showing the environment and the many factors that the user is able to modify to create the virtual reality environment. Directly below the main viewing window is a secondary window showing the environment in the "game mode," or how it would be seen from the proposed cardboard VR HMD.

Hardware

The development of an inexpensive virtual reality environment was fulfilled by utilizing a student's provided smart phone and through the purchase of the

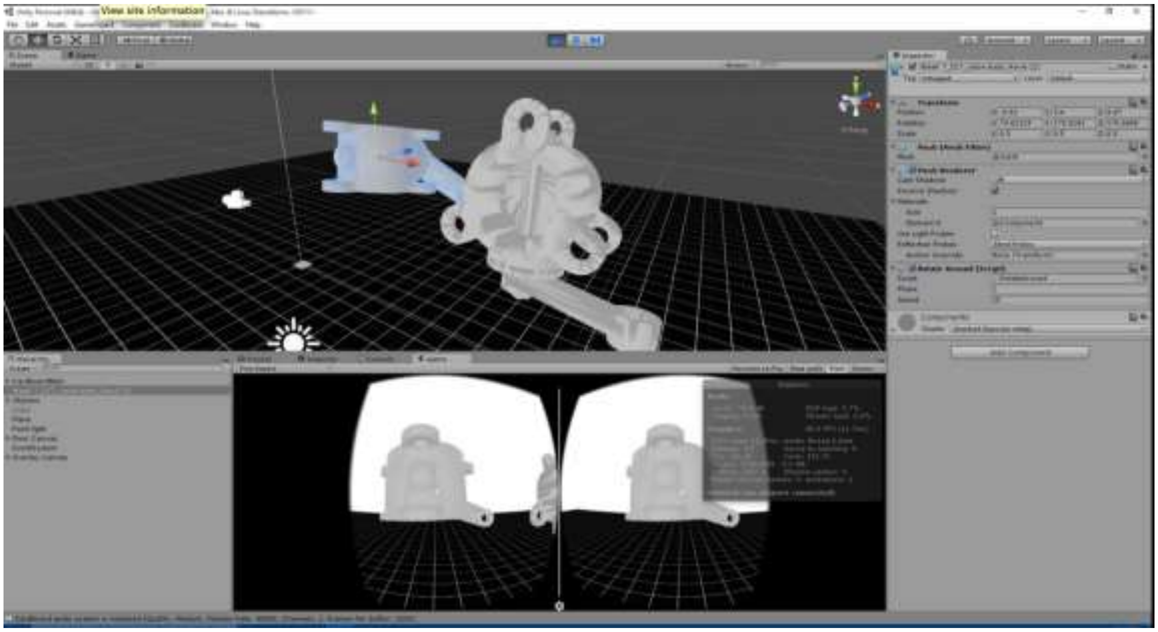

Figure 10. The Unity® game engine interface with main viewing window for editing imported files and the corresponding view that will be presented to the viewer using the developed Android smart phone application.

Source: Pooler, C. J., & Vaccari, S. (2016, April 8). MECH 100 Virtual Reality Application [Android .apk]. Chico, CA.

appropriately sized cardboard HMD display. These displays range in size based on the dimensions of the device in question. These HMDs vary in price, from free samples up to $25.00, and are readily available online at most retailers. The cardboard interface was made famous by Google engineers David Coz and Damien Henry when first introduced in 2014. As of January 2016, over 5 million google cardboard HMDs have been shipped, and over 1,000 applications for smart-devices have been developed.

Components for these cardboard HMDs range but normally consist of several inexpensive components. A sheet of cardboard is cut into desired shape and houses 45mm focal length lenses, magnets, adhesive tape, and other components like rubber bands and Velcro® to keep the unit together. After assembled a smart-device is inserted in front of the focal lenses and software application is launched to display a stereoscopic three-dimensional image for the user. The software application when running has access to applicable technology associated with the smart-device including forward looking cameras, accelerometers, and audio inputs/outputs depending on design.

The application developed for the PSM project was made with the Unity® game engine. After importing the CAD file into Meshlab® and ensuring that secondary processing was complete, the Meshlab® software .obj output was entered into Unity® for testing in the developed virtual reality environment.

Rendering in Unity® is done through the application of shaders, materials, and textures. This is then further enhanced by allowing the game engine to recalculate the vertices from the triangles associated with the surface geometry of an object in the .obj file format. Through a Recalculate Normals function, Unity® can sometimes smooth out these vertices for a higher quality rendering. The Unity® game engine has the capacity to take the imported .obj file format of an object and calculate the normals manually rather than inheriting them from 3D modeling software. An example is shown below, where the researchers investigated different ways to enhance the renderings. Figure 11 illustrates the original inputs with a secondary software shading package applied to try to enhance the renderings. Figure 12 shows the file with the calculated normals from the Unity® software package and the resulting image.

Implementation of Virtual Reality

The software application in its current state illustrates what is possible as far as the creation of an inexpensive virtual reality environment for undergraduate education.

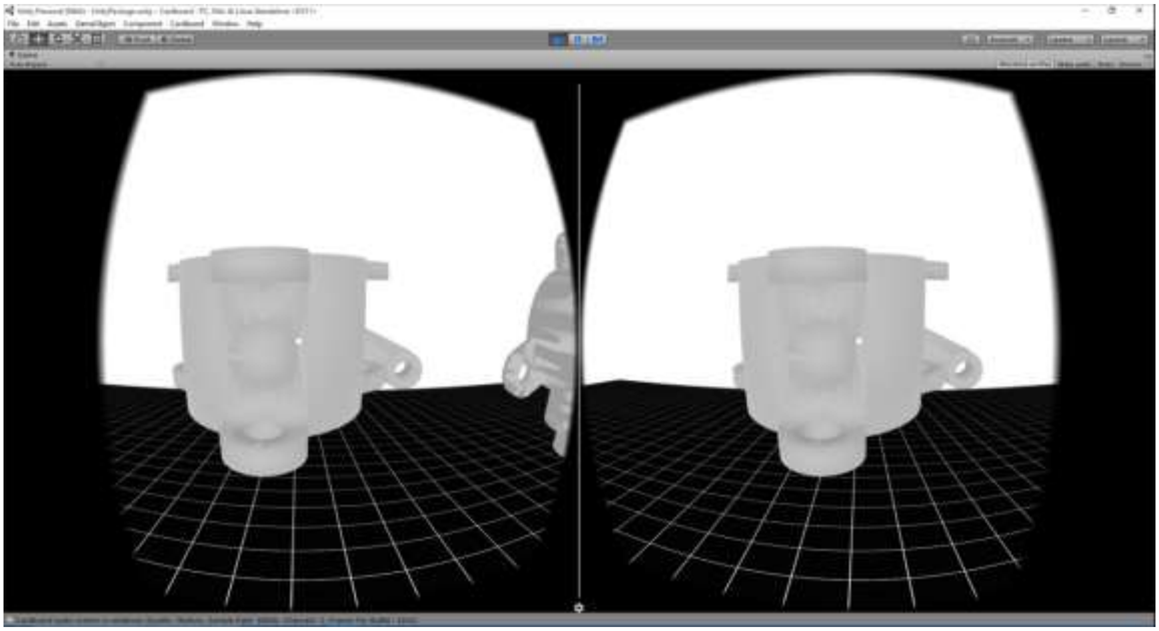

Figure 11: Unity 3D® application depicting the resulting smart-device Android application poor view quality prior to Unity 3D® normal calculations. Evaluations of other methods to create better surface geometry were pursued using various open source applications.

Source: Pooler, C. J., & Vaccari, S. (2016, April 8). MECH 100 Virtual Reality Application [Android .apk]. Chico, CA.

Given the scope of the project and the limited time frame investigations into more complex user interfaces were not investigated. The researchers decided that above all simplicity in use was paramount in the design of the virtual reality application.

The Android® .apk was made available for student use April 11th. The current application has a series of four different scenes. Each scene consists of an instructor created virtual environment with a corresponding virtual file available for investigation. By navigating through the main menu, a student user is able to select one of three examples of a valve body assembly to investigate, with an optional fourth scene that is customizable for the student to manipulate. The first scene in the main menu shows the

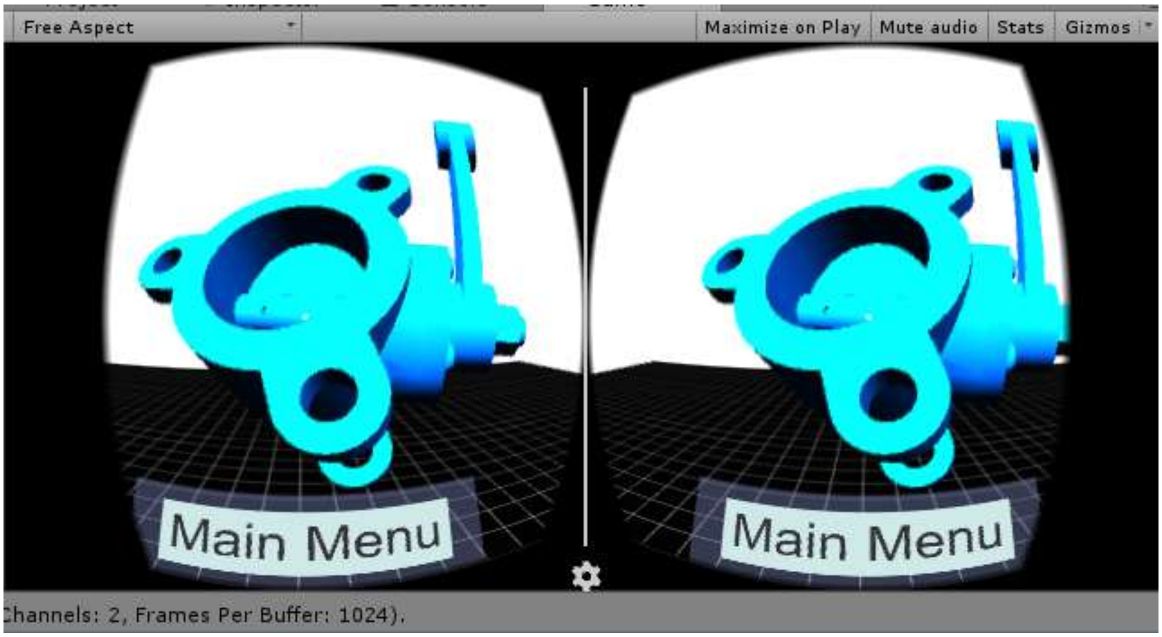

Figure 12. A picture of the final Android .apk product using the available Unity 3D® normal calculations option.

Source: VR application developed for PSM project. Pooler, C. J., & Vaccari, S. (2016, April 8). MECH 100 Virtual Reality Application [Android .apk]. Chico, CA.

valve body completely assembled, and students are able to investigate the assembly in a virtual environment. By leaning their head left or right, the student's vantage point will rotate around the object a full 360 degrees.

The second scene available for viewing is an example of an exploded view of the same valve body assembly. When a student selects this option from the main menu, the student is able to see the full assembly in an exploded state with all components visible. When the student tilts their head left or right, the view will rotate around the exploded assembly so the student can investigate the exploded assembly in a virtual environment.

The third scene accessible from the main menu allows a student to see a 90˚ assembly cut in an assembled valve body assembly. Again when a student tilts their head left or right, the perspective rotates around the model to expose the student to an infinite number of perspectives. Each of these options have created a virtual environment that allows a student to immerse themselves in a lesson, where they are able to experience an infinite number of perspectives that may allow them to more readily understand and learn the associated material.

The final scene available for students in the main menu is a customizable scene for them to upload their own VR files. The researcher provided the students with instructions for use, and is allowing the students in MECH 100 Lecture the ability to experience VR on their own terms. By creating this option, students can use this scene to investigate other assignments for viewing them in a three-dimensional environment. This customizable environment is still limited to a few constraints. At this time, depending on the hardware of the associated Android phone, more complex models may prove difficult for a phone to render.

Students were enthusiastic about the VR application. At this time, students are beginning to investigate their CAD files in a three-dimensional virtual reality environment for the first time. This investigation is exposing students to multiple perspectives and is hopefully helping in the development of their spatial skills. Interaction is currently limited to the use of the phone's integrated accelerometers and forward-looking cameras to interact with the virtual files. Future work will investigate the integration of inexpensive sensors to mount to the cardboard HMDs to register hand movement so that students will be able to reach out and manipulate these virtual files manually.

CHAPTER IV

FINDINGS AND RESULTS

Discussion

The literature review for the project showed the link between student motivation and the incorporation of mixed reality in the classroom. After the initial discussion with students in MECH 100 at CSUC, there was positive student feedback. Students were enthusiastic about the idea of experimenting with augmented reality in the course. This project outlines the creation and use of augmented and virtual reality was employed where applicable to the lessons and content presented in MECH 100 Lecture. Future research will present the data collected from students concerning student survey feedback and comparison of spatial visualization skills development during the course of the Spring 2016 semester by comparing the results of the PSVT: R pre and post-test results.

Similar Studies using Mixed Reality Environments

Similar research has been conducted concerning augmented reality's incorporation into an engineering graphics communication course at the undergraduate level. The most relevant study for this discussion involved a study conducted by Timothy Thornton at North Carolina State University in 2014. Thornton used augmented reality files in CAD laboratory meetings where students were provided a handheld device with the same Augment® software for students to use during their lessons. The application was running prior to students arriving in lab, and the augmented reality models were used as a visual aid in the creation of a the same part file in CAD software. This model was used as a reference for students to support in their spatial visualization during the creation of their CAD laboratory assignments. This study was one of the main reasons for adopting the Augment® software in CSUC's MECH 100 Lecture Engineering Graphics I course.

In addition, the researchers at North Carolina also utilized the PSVT: R as an assessment tool for their students' spatial visualization scores. The researchers required students whom participated in the study to take the PSVT: R and the *Motivated Strategies for Learning Questionnaire* (MSLQ). These scores were aggregated and compared using a paired T-test to measure the mean scores of the pre and post-tests.

The researcher for this PSM found this means of implementation effective but the two projects differ in content and scope. The first difference being the types of exercises used by the students in instruction. The augmented reality files created for MECH 100 Lecture were not used as a supplemental tool in the creation of CAD models in a laboratory setting. The files generated for MECH 100 lab were used to illustrate lecture topics that included examples of third angle projection, examples of section and auxiliary views, and examples of collapsed and exploded assemblies. Students in MECH 100 Lecture used the augmented reality files as a tool finish their homework. The use of the augmented reality files in MECH 100 Lecture primarily aided students in their hand sketching skill development, not their CAD skills development.

The use of assessment was also addressed for the CSUC PSM project. The North Carolina study presented that the results from the administration of the PSVT: R and MSLQ had mixed results. The MSLQ paired T-test showed no significant difference between pre and post-test results, while the PSVT: R showed a significant difference with a p-value less than 0.01. Based on the findings from this conclusion, the researcher decided that the use of the PSVT: R would be the primary means of assessment in the future for determining an association between the use of augmented reality in instruction and improved spatial visualization skills.

The North Carolina study was an excellent example of the implications that augmented reality has on the link between the incorporation of augmented reality technology in undergraduate engineering education. The CSUC study deviated again from the North Carolina research by aiding in the development of a virtual reality environment with an inexpensive cardboard HMD for student use. Although this technology is in its development stages, VR’s role in undergraduate engineering instruction was examined and met with enthusiasm with the MECH 100 Lecture students at CSUC. The CSUC PSM project is significant in that as of the time of this publication, the use of an inexpensive cardboard VR HMDs in undergraduate engineering instruction is not a thoroughly researched topic. Based on the information uncovered in the literature review, this topic would be a good avenue to investigate for future research.

Another groundbreaking study was conducted at La Laguna University by Jorge Martín-Gutiérrez, Manuel Contero, and Mariano Alcañiz. La Laguna University has recognized the importance of spatial visualization skills development in their engineering curricula. Martín-Gutiérrez, García-Domínguez, Roca-González, Sanjuán-HernanPérez, & Mato-Carrodeguas (2015) elaborated on their use of a AR tool they used in a spatial visualization development course administered at La Laguna University. The instruction consisted of five levels of increasing difficulty ranging from level one being the easier tier, and level five being the most difficult. The study used the *Differential Aptitude test* or DAT-5:SR Level 2, and the *Mental Rotations Test* (MRT) for student assessment. It was determined that the researchers' efforts to enhance the spatial visualization skills through the incorporation of augmented reality technology in instruction enhanced the students scores and that there was a significant difference in the MRT scores of students whom were administered the pre and post MRT tests with a p-value of 0.009.

Martín-Gutiérrez et al. (2013) conducted another study comparing the spatial visualization skills development in undergraduate engineering students by evaluating the use of VR, AR, and PDF3D technologies against a control group of students. The intention of this research was to determine which of the three tools would provide the best means of instruction based on the academic performance of the associated students. The study concluded that the scores of the students exposed to VR, AR, and PDF3D technologies were all higher than the students in the control group. Of the three modes of mixed reality technologies, the students whom specifically were exposed to AR technology performed better on average than VR and PDF3D technologies.

Each of these studies proved useful in the development of the CSUC PSM project. Through the research previously conducted on augmented and virtual reality's use in undergraduate engineering education the researcher for the CSUC PSM study was able to better align instructional augmented and virtual reality interventions for spatial and visualization skills development. In addition to the presented examples of AR and VR enhanced instruction, the selection and examination of an appropriate assessment tool was identified and recommended for implementation into the MECH 100 Lecture Engineering Graphics I course at CSUC. The use and evaluation of the PSVT: R as an assessment tool at CSUC in MECH 100 Lab Engineering Graphics I will be examined and presented in future research concerning the role that augmented and virtual reality intervention plays in the development spatial visualization skills undergraduate engineering students at CSUC.

CHAPTER V

THE CONCLUSIONS AND RECOMMENDATIONS

Chapter five discusses the results of the project, and examines the project details, the conclusions drawn, and potential areas for future study after the conclusion of the project. A summary of the project will include the project details and the opportunities and obstacles experienced. These issues discovered during the project's duration will be addressed as well as suggestions that may provide adequate solutions for future projects.

Summary

The incorporation of mixed reality media in the classroom may have an impact on spatial visualization skills. There is still the possibility that students can increase their spatial visualization skills by another variable other than augmented reality exposure. Given the constraints of the project, providing a controlled atmosphere with set evaluations proved impossible for the researcher to achieve. To truly investigate the link between the growth of spatial visualization skills and augmented and virtual reality, a more conclusive environment for testing must be provided to gather accurate data. For the Professional Sciences Master's Project the creation and implementation of mixed reality media was pursued to help a diverse engineering student population with their spatial visualization skills as well as to motivate them in a mixed reality and a technologically diverse learning environment. The researcher believes that this was achieved during the course of the project, and will continue to develop additional content for future courses.

The information gathered during this project can be applied outside of engineering graphics. The incorporation of mixed reality is gradually finding its way into day to day life. It makes no logical sense to limit this technology to solely students enrolled in engineering disciplines. Augmented reality technology has a tremendous and currently untapped potential for all areas of study within the university setting. As discussed in the literature review, lack of adequate training remains the largest barrier to entry. This project was exercised with cost as a major factor in the selection and application of each software package, and proves that cost is no longer a barrier due to the availability of free packages for faculty and students.

The ability for mixed reality technology to allow a student to experience multiple perspectives enhances learning and retention. By creating a technologically advanced augmented or virtual environment, students can experience realities not possible in a traditional classroom environment. Engineering graphics students can manually manipulate models, physics students can shrink to the size of an atom for a physics lesson, and physiology students can use augmented reality to project skeletal formations on their body to study for an upcoming anatomy test. Each application provides a more immersive and inclusive experience, which obviously extends well beyond traditional two-dimensional based learning.

Creating a learning environment that incorporates mixed reality technology intrigues students, and retains their attention during the associated exercises. Mixed reality media use in class translates to increased student motivation in each case that the technology is applied. Students lives are becoming increasingly technologically sophisticated, but their learning environments are not adapting as quickly as their personal lives. For universities to stay competitive they too must be willing to incorporate newer more untraditional teaching techniques with the tried and true practices to better align with their student populations.

Future Projects

To quantify the benefit of mixed reality media in instruction the use of student surveys and spatial visualization assessment tools will be implemented and examined in future work. Short term research will focus on the initial offering of these mixed reality files to the Spring 2016 MECH 100 Lecture course but to thoroughly examine the impacts of augmented and virtual reality spatial visualization development longitudinal studies would be ideal. An in depth analysis of a student's development may entail following their development throughout their college career by monitoring their grade point average in upper division graphics courses.

One of the limitations of the project was the inability to develop two software applications simultaneously by the proposed deadline to better serve the range of mobile devices present in the classroom. Future projects will advance the development of mobile applications for IOS devices for student users with Apple® devices. Only after developing and making these applications available to students will mobile device HMD displays be readily accessible for student use in the classroom.

One of the most promising future projects that should be pursued by CSUC is the creation of an introductory course in spatial visualization training for underperforming engineering majors that uses augmented reality to supplement the associated spatial visualization training. Courses like this have been initiated at other institutions through a partnership with research provided by studies backed by the National Science Foundation. A similar introductory course should be offered to perspective CSUC engineering students whom have been diagnosed as underperforming using the PSVT: R as the assessment tool.

In addition, students whom desire to pursue an engineering degree at CSUC are already required to take and pass a calculus readiness exam prior to enrolling for class. Based on the literature review, there is a direct correlation between special visualization skills and engineering student success. In an effort to be more effective at pinpointing individual freshman engineering students whom require additional spatial visualization training, the PSVT: R test should be incorporated into the application process for the entire College of Engineering. By administering the test via an online learning platform like Blackboard®, the College of Engineering administration may be better able to assess the status of incoming freshman students' levels of spatial training, and initiate a spatial training intervention earlier in the students' educational career. The Blackboard® platform allows for immediate and actionable datasets compared to the necessity of administering a paper calculus readiness exam in person. The incorporation of this test may help with the issue of STEM diversity and gender gaps, reduce engineering student dropout rates by increasing student retention, and increase engineering student graduation rates. The PSVT: R can also be administered prior to graduation, to assess how students' spatial visualization skills have been impacted over their tenure at the university, and may be included in college-level accreditation documentation. Future research will include the use of the PSVT: R as an assessment tool to test the impact that augmented and virtual reality media has on spatial skills development for college level engineering graphics majors.

Conclusions

The incorporation of mixed reality in an undergraduate engineering graphics course at CSUC to technologically update the learning environment for students was derived from personal experience with the technology, as well as by the information collected during the literature review for the project. The literature review confirmed personal suspicions that student motivation was influenced by the use of technology like augmented and virtual reality in the classroom environment. After investigating the possible methodologies that mixed reality could bring to the classroom, it was evident that the technologies could play a major role in developing an aspiring engineering student's spatial visualization skills. Spatial skills development was mentioned in previous iterations of the engineering graphics course taught by various instructors in the past, but there was little effort undertaken to develop, let alone assess incoming engineering freshman's level and extent of their respective spatial abilities.

The literature review was also what brought the incorporation of the PSVT: R into the MECH 100 course as an accurate assessment tool to test a student's spatial visualization skills. These students that underperform spatially may benefit from additional spatial skills training. By providing this assessment to students early on, instructors may be able to initiate interventions sooner to increase their retention, and prevent these students from giving up on their engineering degrees.

The results of the project all indicated that student benefited from the incorporation of mixed reality technology in the classroom, although no definitive conclusions can be drawn from the project deliverables. Spatial skills may have been developed via other means, and cannot be directly attributed to the infusion of mixed reality content. Only after personal discussions and feedback from student participants, was the researcher able to ascertain the impact that this technology had on a student's learning environment.

Recommendations

It is the researcher's recommendation that the College of Engineering include the PSVT: R into the assessment regime for incoming freshman engineering students. Students whom test scores fall below a certain threshold will be automatically enrolled into a spatial visualization training course, and have the opportUnity to utilize augmented and virtual reality to assist in the training program.

Augmented and virtual reality also has the capacity to create more immersive laboratory learning laboratory environments as well. There have been numerous studies outlining the incorporation of virtual laboratories for university students. These virtual laboratories allow students the ability to conduct experiments without stepping foot in the actual physical laboratory. Students can conduct these labs in a safe, but immersive environment at their own pace from the comfort of their home. This is desirable from the perspective of the institution, whom is running into increased student enrollment and is faced with limited lab space and materials for students to utilize. This is also advantageous for students whom may feel rushed, or uncomfortable in the laboratory environment, but would be comfortable running a simulation in a safe but immersive environment. To deliver this experience to students, the instructor must create an environment where the student experiences the right amount of presence in that learning environment, while providing for a vivid and immersive but safe computer-generated laboratory experience.

Finally, it is the researcher's recommendation that the CSU develop faculty in the development and implementation of mixed reality media for each of their associated disciplines. Currently, CSUC has resources available for faculty to aid in course development concerning technological content advancement. The *Technology Learning Program* (TLP) located on campus currently serves CSUC faculty regarding technological elements that pertain to teaching and learning. Their expertise ranges from online learning platforms like Blackboard, to mobile devices, and their associated university endorsed applications. After conducting research into the application and resulting success regarding mixed reality in the classroom, the researcher suggests that the TLP hire staff designated on assisting faculty members on the development and implementation of augmented reality in the classroom for CSUC faculty members.

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