THESIS

INTEGRATION AND EVALUATION OF VIRTUAL REALITY IN DISTANCE MEDICAL EDUCATION

Submitted by

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ABSTRACT

INTEGRATION AND EVALUATION OF VIRTUAL REALITY IN DISTANCE MEDICAL EDUCATION

The need for distance education is ever increasing, and it is therefore essential to continue advancing distanced pedagogical techniques to provide exceptional and equitable education to students. Previous studies suggest that virtual reality (VR) provides unique benefits to the remote learner through several important areas: 1) providing an environment which can be readily manipulated to serve needs of diverse learner, 2) promoting a feeling of social presence by connecting students in a common virtual environment, 3) holding learner attention and engagement, and 4) challenging learners to take an active role in their learning to derive their own meaning from content presented. Each of these points addresses a key challenge imposed by traditional distance education methods, so further exploration and refinement of VR in distance education is important.

The following chapters dive into two studies that explore the role of VR in distance education in human anatomy classrooms. Chapter 1 provides an overarching literature review of distance education including common methods, challenges, and the effect of the global COVID-19 pandemic on remote instruction methods. The chapter further introduces virtual reality, discussing its current role in education and providing an overview of current areas of VR research in education. The methodology used for each study is briefly discussed.

Chapter 2 is a modified version of a manuscript currently in review. This chapter is composed of a longitudinal study conducted on undergraduate students in a human anatomy course at Colorado State University. Covid-19 restrictions and the resulting demand for online instruction posed challenges to education communities worldwide, especially in human anatomy. In response, Colorado State University coordinated and deployed an 8-week long large-scale virtual reality (VR) course to supplement online human anatomy instruction. Students [n = 75] received a VR capable laptop and head-mounted display and participated in weekly synchronous group laboratory sessions with instructors. The program enabled students to remotely collaborate in a common virtual space to learn human anatomy on an artist-rendered cadaver. Qualitative data were collected on student engagement, confidence, and reactions to the new technology. Quantitative data assessed student knowledge acquisition and retention of anatomical spatial relationships. Results and implications are discussed. This VR based course demonstrates an interactive approach to distance education and may further promote educational research utilization of VR to supplement teaching human anatomy.

Chapter 3 is also a modified version of a manuscript under review. This chapter is composed of a second longitudinal study that evaluated the utilization of virtual reality (VR) as a novel tool to promote virtual connection and collaboration by remotely connecting rural high school students to graduate student mentors to learn human anatomy in a VR, case-based course. It was hypothesized that 1) VR is an effective tool to remotely link graduate student mentors with high school students, promoting student engagement and motivation, and 2) this VR, case-based curriculum promotes skills for student success (i.e., problem solving, spatial ability, communication, and collaborative skills). Qualitative data assessed student motivation, mentorship engagement, satisfaction, and overall perceptions while utilizing the VR program compared to traditional online methods. Quantitative data assessed changes in student critical thinking ability throughout the semester. Results and implications are discussed at length. Research on the implementation of virtual reality in education is in its early stages, but there is a growing need to investigate the effectiveness of immersive technologies in overcoming barriers to distance learning. The presented course is an early exploration of how VR can enhance STEM teaching, improve student learning experiences, and prepare students for success in higher education.

Chapter 4 presents a broad summary and conclusion of the role of VR in distance education explored in the preceding manuscripts. Broad reaching implications are discussed, as well as recommendations for implementing VR into classrooms.

These studies were designed to evaluate the role of VR in distance education at multiple levels of education. Each of the studies presented provide strong evidence that VR is a highly collaborative and engaging tool that has the potential to address important challenges posed by traditional education methods. Virtual reality is an emerging, cutting-edge technology that may transform distanced education into a more connective, collaborative, and engaging method of exceptional and equitable virtual learning.

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When my father passed away a year into my graduate program, I was astounded at the level of love and support that came from the people listed above, and from my family. Thank you so much for your grace, kindness, advice, and patience during this time – I am so grateful.

DEDICATION

For my father, now passed, who always, always believed in me.

For my mother, the strongest and most grace-full woman, who never left my side.

And for my sister Abby, who kept me human through everything.

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CHAPTER 1 : INTRODUCTION

1.1 LITERATURE REVIEW

1.1.1 Distance Education – An Overview

Distance education is essential to the infrastructure of modern education. Once viewed as an exclusively alternative form of education, distance education is becoming a mainstream mode of learning with demand continually increasing (Johnson, 2020; National Center for Education Statistics, 2018). Approximately 3.1 million students enrolled in exclusively online coursework at Title IV institutions in 2017, with an additional 3.5 million postsecondary students taking at least one online course (National Center for Education Statistics, 2018). In total, approximately 6.7 million students at post-secondary institutions enrolled in at least one online course in 2017, comprising one third of all university students (Johnson, 2020). Further, the percentage of students enrolling in exclusively online coursework has jumped from 11.3% in 2012 to 15.4% in 2017, demonstrating that demand is and will continue to expand (Ginder et al., 2018; Lederman, 2018).

The term "distance education" refers to the physical spatial and temporal separation of student and instructor, with instruction, learning, communication, and course resources offered through virtual modalities (Anderson & Rivera-Vargas, 2020). Methods include *asynchronous* and *synchronous* delivery, and courses typically administer more than 80% of content online (Allen & Seaman, 2011). Synchronous methods have been made possible by advancements in technology and include real-time online interactions with instructor and/or peers. Synchronous instruction is often offered through online platforms such as ZOOM, Skype, Microsoft Teams, and others (Khan, 2006; Shahabadi & Uplane, 2015). Facilitations vary widely, but can include livestreamed lectures, group seminar-style discussions with video platforms, student presentations using a screen-sharing tool, or small-group work in virtual breakout rooms. Synchronous learning is a relatively new development, thanks to innovations like broad-band internet connections, computers, and online video platforms.

Asynchronous learning has been a staple of distance education for decades, existing without the constraints of time. Before technological advancements, asynchronous learning was made possible by mailing course materials to students, paper assignments, and using email as a primary mode of communication. Today, asynchronous learning primarily relies on online tools to boost engagement such as pre-recorded lecture material and online discussion forums to humanize interactions (Shahabadi & Uplane, 2015). Due to its availability anytime and anywhere, asynchronous coursework may appeal to a broader base of learners who have time constraints or responsibilities that preclude joining a scheduled class.

Prior to the COVID-19 pandemic, distance education was primarily utilized by learners separated from their institutions by great distances, often in rural locations or hindered by poverty (Pregowska et al., 2021). It also enabled remote learning to be utilized by learners with disabilities that prevented class attendance, and adult learners balancing education with a full-time job and/or family responsibilities (Pregowska et al., 2021). The broad accessibility, affordability, and flexibility of online learning has allowed learners from varied backgrounds to expand their knowledge and learn something new (Pregowska et al., 2021).

1.1.2 Challenges of Distance Education

Although many inclusive benefits of distance education have been reported, some studies have suggested that online learning can increase student-perceived social isolation, feelings of disconnection, boredom, impaired group cohesion, and distraction from learning (Cesari et al., 2021). Online learning can be prone to student distraction via internet advertisement, social media pull and other outlets, and these detractions from focused learning can negatively impact student engagement, attention, and perceived state of flow (Cesari et al., 2021; Pregowska et al., 2021). The increasing demand for distance education invites the exploration of virtual pedagogical methods and education modalities that promote learner attention, engagement, and competency in desired skills.

Though many effective methods have been developed for online classrooms, laboratories remain difficult to effectively replicate in an online environment due to their hands-on nature. In physical science, chemistry and biology, course evaluations of a few carefully designed online laboratories have demonstrated equivalent student outcomes and perceptions/attitudes when compared to traditional face-to-face laboratories (Brinson, 2015; Dyrberg, 2017; Penn & Ramnarain, 2019). However, hands-on laboratories can be more difficult to replicate in an online environment because students are limited in their ability to interact with laboratory materials (Moosvi et al., 2019; Sivrikaya, 2019).

Few studies have been published on the deployment and efficacy of fully online human gross anatomy laboratories. Traditional prosection and dissection laboratories are hands-on in nature, requiring physical cadavers and group work (Azer et al., 2007; Huitt et al., 2015; Nieder et al., 2005; Vasan et al., 2008). Although the utilization of online resources as a supplement to in-person human gross anatomy laboratories is well studied (Brucoli et al., 2018; Doubleday et al., 2011; Fleagle et al., 2018; Mitrousias et al., 2018; Swinnerton et al., 2017; VanNuland et al., 2016) fully online anatomy laboratories remain a relatively un-studied niche. Attardi and Rogers (2015) designed an online laboratory in which instructors used Netter's 3D anatomy and connected synchronously with students, who were able to interact via a chat box. There was no difference in final grades between the online and on-campus laboratories, and results suggested that course performance was not dependent on instruction modality, but previous academic performance (Attardi & Rogers, 2015). This course was later modified to improve student engagement by increasing virtual interaction opportunities with instructors and peers using breakout virtual laboratory groups. These virtual breakout laboratory groups improved engagement but did not match F2F laboratories (Attardi et al., 2018).

Another fully online human gross anatomy laboratory assessed student performance and perceptions taking either an in-person prosection laboratory or an online laboratory utilizing AnatomyTV (Mathiowetz et al., 2016). Compared to the online AnatomyTV group, F2F students received final course scores that were significantly higher (87.25% and 90.47%, respectively, $p = 0.02$) and rated significantly higher on self-perceived learning and satisfaction.

These results provide evidence for the validity and importance of online anatomy instruction but suggest that further research and curricular advancements are warranted to refine student engagement in online anatomy laboratories. It is important to continue exploring novel instruction methods in full-scale online human anatomy laboratories to provide a high-quality learning experience for students that maintains performance, engagement, and motivation.

1.1.3 Effective Learning: Engagement, Critical Thinking, and Spatial Ability

According to Shulman (2005), "learning begins with student engagement." Engagement has long been a subject of interest in educational literature and is commonly agreed to be a multifactorial construct that includes three primary subcategories: behavioral, emotional, and cognitive engagement (Fredericks et al., 2004; Trowler, 2010). Behavioral engagement is defined by observable actions such as completion of coursework or class participation; emotional engagement includes emotional perceptions of and reactions to content; cognitive engagement refers to the metacognitive effort students undertake to grasp concepts (Lee et al., 2021). The term "engagement" has been defined by many, but the following definition by Axelson and Flick (2010) encompasses the essential components. Engagement can be defined by "how involved or interested students appear to be in their learning and how connected they are to their classes, their institutions, and each other" (Axelson & Flick, 2010).

Educators and researchers have investigated the role of engagement in the student learning experience for over 70 years, perhaps because research has established strong relationships between high engagement and positive student outcomes including high levels of learner satisfaction, persistence, academic achievement, and social engagement" (Groccia, 2018; Trowler, 2010). Due to this correlation, it is critical to explore pedagogical methods that provide high levels of engagement for students, as this directly affects their performance, satisfaction, and overall learning experience. This is especially important in online learning, with its proclivity for student distraction and perceived social isolation, all of which may detract from student engagement and performance.

Students who develop robust critical thinking skills are well prepared for future schooling and/or industry. Critical thinking skills are valuable in almost every area of life, allowing individuals to make sound judgements and inquiry based on information presented to them (Evans, 2020; Facione, 1990). There is little debate on the importance of developing critical thinking skills during schooling years; however, researchers are still investigating effective pedagogical methods for developing student critical thinking ability (Abrami et al., 2015). Additionally, there is a need to evaluate development of critical thinking ability in online learning, as the need for online learning continues to increase. The study presented in Chapter 3 aims to address this need, evaluating the role of VR in development of student critical thinking ability in an online classroom.

Lastly, high spatial ability has been repeatedly linked to improved student performance, especially in spatially complex subjects such as human anatomy. Learning human anatomy is a highly spatial activity and involves a thorough understanding of structural relationships (Langlois et al., 2017). A strong foundation in anatomical structural relationships prepares pre-medical students for professional careers that utilize cross sectional imaging such as MRI and CT scanning. Literature has previously shown that students with higher spatial abilities perform better on laboratory examinations and cross-sectional understanding (Guillot et al., 2007; Langlois et al., 2017; Lufler et al., 2012). Further, previous studies have demonstrated that students with below-average spatial ability can improve their skills with effective interventions, which often correspond to an increase in academic performance. It is therefore important to explore novel tools that enhance student spatial ability, especially in spatially important subjects such as human anatomy.

Limited research has been conducted on the role of virtual reality in improving student spatial ability. Traditionally, anatomy students are exposed to structural relationships while dissecting a cadaver or viewing a prosected cadaver (previously dissected). More recently, researchers have begun investigating novel methods to improve student spatial abilities in virtual environments. Initial evidence on the relationship between VR usage and the understanding and retention of anatomical spatial relationships suggests that VR is as good as or better than traditional methods (Ekstrand et al., 2018; Moro et al., 2017), but more research is needed to better quantify the role of VR in developing student spatial ability.

1.1.4 Virtual Reality

The concept of VR can be dated back to the 1960s when Ivan Sutherland developed the first head-mounted display capable of tracking head movements (LaViola et al., 2017). Recent improvements in tracking, display, and graphics processor units have led to greater accessibility of VR-capable personal computers and expanded use of VR programs in areas such as anatomy education, neurosurgery, quantum chemistry, geology, and many other areas of study (Basantes et al., 2017; Meola et al., 2017; Salvadori et al., 2016; Stepan et al., 2017).

During the past five years, and specifically since COVID-19, virtual reality (VR) has emerged as a novel tool for immersive learning that may prove especially useful in developing effective virtual laboratories and rural outreach efforts. In contrast to traditional two-dimensional (2D) methods of online instruction, VR allows learners to be fully immersed in a three-dimensional environment, in which they can interact with and fully explore the material. VR also enables multiple students to collaborate in a common virtual environment independent of location (Ardiny & Khanmirza, 2018). Virtual Reality (VR) has become an increasingly popular area of study for use in human anatomy education to provide unique perspectives and learning opportunities such as remote instruction.

Previous studies have demonstrated that utilization of VR in anatomy and neuroanatomy classrooms provides intrinsic learning benefits, promoting student motivation, satisfaction, engagement, immersion, and perceived usefulness compared to traditional paper-based study methods (Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017). In addition, students using VR or augmented reality (AR) have shown equivalent or better learning outcomes compared to control methods in anatomy, neuroanatomy, physical science, and chemistry, which demonstrates that VR does not detract from (and may in fact promote) student performance (Altmeyer et al., 2020; Dunnagan et al., 2020; Moro et al., 2017; Stepan et al., 2017). While the results of these in-person studies are promising, comparatively few studies have explored the role of VR as a tool in distance education. It is unclear how the use of VR in a fully remote environment can benefit the online learner and more research is needed to better quantify the role of VR in the classroom.

1.2 METHODOLOGY

The studies presented in chapters 2 and 3 used a mixed methods approach, which includes both qualitative and quantitative data. Quantitative data, including measurable metrics, evaluated student exam scores, student presentation scores, and Likert scale data to assess student perceptions of using virtual reality. Qualitative data was also collected in each study to further corroborate findings of quantitative data, and to provide a more well-rounded perspective on student experience using the VR program in a distanced classroom. Data was collected in the form of focus group interviews, which were analyzed for primary themes by two independent researchers and later finalized as a team.

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CHAPTER 2 : A LARGE-SCALE VIRTUAL REALITY DEPLOYMENT: A NOVEL APPROACH TO DISTANCE EDUCATION IN HUMAN ANATOMY[1]

2.1 INTRODUCTION

Various remote instruction options at all levels of education have been continuously developed and utilized over the last 20 years (Seaman et al., 2018) to accommodate learners who are non-traditional (working full time and/or with children), from rural communities (with long commutes), or otherwise require a greater degree of flexibility in coursework modalities (Allen et al., 2002; Ally, 2008; Boling et al., 2012; Naidu, 2014). Students have stated that distance education enabled them to continue their education by overcoming many obstacles (Bagiacik, 2019). In fall of 2018, around 6.9 million students were enrolled in distance education courses at degree-granting postsecondary institutions in the United States, which is an increase of 300,000 students compared to fall 2017 (National Center for Education Statistics, 2019).

As a result of the Covid-19 pandemic in 2020, a rapid and massive global shift to remote coursework became necessary and many more institutions started to offer their coursework either fully online or in a hybrid format. This sudden shift was challenging for gross anatomy laboratories, who traditionally rely heavily on in-person group work and hands-on activities. Harmon et al. compared anatomy education before and during the pandemic and denoted a decrease in in-person lectures and use of cadaveric material during Covid-19 and an increase in computer-based assessments utilizing images (Harmon et al., 2020). Rapid communication and video conferencing was provided by the use of various online platforms such as Zoom, Chime,

[1]This chapter is a modified version of *A Large-Scale Virtual Reality Deployment: A Novel Approach to Distance Education in Human Anatomy,* currently under review in *Medical Science Educator.* List of authors: Natascha Heise*, Katelyn Brown*, Chad M. Eitel, Jordan Nelson, Brendan A. Garbe, Carolyn A. Meyer, Kenneth R. Ivie Jr., Tod R. Clapp (* indicates equal contribution)

Webex, Microsoft Teams, and GDrive (Kumar & Kumar, 2019). Furthermore, the use of in-house created content and Complete Anatomy software as a digital teaching resource increased (Harmon et al., 2020).

Though this shift enabled the continuation of anatomy instruction, the repercussions of the pandemic and change to online instruction have been well documented by anatomists and students (Kumar & Kumar, 2019; Evans et al., 2020; Franchi, 2020; Gupta & Pandey, 2020; Jones, 2020; Longhurst et al., 2020; Pather et al., 2020; Ravi, 2020; Singal et al., 2020). A detailed thematic analysis of multiple institutions revealed loss of integrated "hands-on" experiences, changes in workload, and challenging anatomists' personal educational philosophies (Pather et al., 2020). With that change, studies reported that these laboratories struggled to hold student motivation and to provide interactive engagement opportunities that would result in a comparable learning experience to traditional face-to-face (F2F) laboratories. It is therefore of no surprise that online medical laboratories have become an increasingly popular area of research as instructors work to increase accessibility of their coursework, increase student outcomes, and to accommodate increasingly diverse populations and locations of learners. Due to this growing trend of creating online learning alternatives, medical education will likely undergo a true paradigm shift in the next decade, which may fundamentally alter how medicine is taught and practiced.

2.1.1 Online Human Anatomy Laboratories

Comparatively few studies have been published in the past on the deployment and efficacy of fully online human gross anatomy laboratories, perhaps in part because prosection and dissection laboratories are hands-on in nature, traditionally requiring physical cadavers and group work (Axer & Eizenberg, 2007; Cahill & Dalley, 1990; Huitt et al., 2015; Jones, 1997; Kamei et al., 2012; Nieder et al., 2005; Nnodim, 1997a; Nnodim, 1997b; Vasan et al., 2008; Whelan et al, 2016; Yeager & Young, 1992; Yeager, 1996;). Although the utilization of online resources as a supplement to in-person human gross anatomy laboratories is well studied (Brucoli et al., 2018; Doubleday et al., 2011; Fleagle et al., 2018; Mitrousias et al., 2018; Swinnerton et al., 2017; VanNuland & Rogers, 2016;), fully online anatomy laboratories remain a relatively un-studied niche. Attardi and Rogers (2015) designed an online laboratory in which instructors used Netter's 3D anatomy and connected synchronously with students, who were able to interact via a chat box. There was no difference in final grades between the online and on-campus laboratories, and results suggested that course performance was not dependent on instruction modality, but previous academic performance (Attardi & Rogers, 2015). This course was later modified to improve student engagement by increasing virtual interaction opportunities with instructors and peers using breakout virtual laboratory groups (Attardi & Rogers, 2018). These virtual breakout laboratory groups improved engagement but were not comparable to the F2F laboratories (Attardi & Rogers, 2018).

Another fully online human gross anatomy laboratory assessed student performance and perceptions taking either an in-person prosection laboratory or an online laboratory utilizing AnatomyTV (Mathiowetz et al., 2016). Compared to the online AnatomyTV group, F2F students received final course scores that were significantly higher (87.25% and 90.47%, respectively, $p = 0.02$) and rated significantly higher on self-perceived learning and satisfaction.

These results provide evidence for the validity and importance of online anatomy instruction but suggest that further research and curricular advancements should continue to refine student engagement in online anatomy laboratories. It is important to continue exploring novel instruction methods in full-scale online human anatomy laboratories to provide a high-quality learning experience for students that maintains performance, engagement, and motivation.

2.1.2 Virtual Reality

Virtual Reality (VR) has become an increasingly popular area of study for use in human anatomy education to provide unique perspectives and learning opportunities such as remote instruction. The "versatile functionality and lightweight form" (Lewis et al., 2013) of anatomy applications make it easy for students to grasp anatomy in a multidimensional manner that, in the case of some programs, allows for additional learning through highly detailed and supplemental information. This can be of special importance when in-person instruction is not available. The concept of VR can be dated back to the 1960s when Ivan Sutherland developed the first head-mounted display capable of tracking head movements (LaViola et al., 2017). Improvements in tracking and display, led to the popularity and availability of VR capable personal computers and the expanded use of VR programs in areas such as anatomy education, neurosurgery, quantum chemistry, geology, and many other areas of study (Basantes et al., 2017; Meola et al., 2017; Salvadori et al., 2016; Stepan et al., 2017).

In several studies, VR has been shown to improve student motivation and engagement in neuroanatomy and human gross anatomy classrooms. Additionally, these studies report no statistically significant difference in quiz scores when compared to non-VR methods (Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017). Students studying neuroanatomy using VR have reported higher satisfaction (Estrand et al., 2018), motivation, engagement, immersion, and perceived usefulness (Moro et al., 2017; Stepan et al., 2017) when compared to control groups using paper-based study methods. Additionally, students have demonstrated equivalent or greater knowledge retention in anatomical content compared to paper-based control groups (Moro et al., 2017; Stepan et al., 2017). These findings are corroborated by studies in other subjects, most notably chemistry and physics (Altmeyer et al., 2020; Dunnagan et al., 2020). Iwanaga et al.

reported an increase of the use of Augmented and Virtual Reality was observed to represent anatomical structures in three dimensions and to enable remote instruction during the pandemic (Iwanaga et al., 2020).

2.1.3 Spatial Relationships

Learning human anatomy is a highly spatial activity and involves a thorough understanding of structural relationships (Langlois et al., 2017). Literature has previously shown that students with higher spatial abilities perform better on practical (cadaveric) examinations, 3D mental creation of a two-dimensional (2D) image, and cross-sectional understanding (Guillot et al., 2007; Langlois et al., 2017; Lufler et al., 2012). Traditionally, anatomy students were exposed to structural relationships while dissecting a cadaver but with the shift to more online instruction, researchers have started to investigate novel methods of improving student spatial abilities, in hopes of improving student understanding of anatomical spatial relationships in a virtual environment. There is mixed evidence on the relationship between VR usage and understanding and retention of anatomical spatial relationships, suggesting that VR is as good as or better than traditional methods (Ekstrand et al., 2018; Moro et al., 2017) However, more research is needed in this area to better quantify the relationship between utilization of VR and spatial ability/understanding of spatial relationships.

2.1.4 Summary

Previous literature has established the importance of online laboratories in improving student accessibility to learning and has shown that relatively few studies on effective online human anatomy laboratory instruction have been published. VR has come forth as a novel and increasingly popular method of instruction, providing a high level of student motivation and engagement while maintaining performance. In addition, student spatial ability has been established as a predictor of performance in human anatomy courses, highlighting the importance of focusing on methods of improving student spatial ability and understanding of anatomical spatial relationships. Only a few studies have tested the role of VR in understanding and retention of spatial relationships and most institutions have utilized VR in small, isolated timeframes.

Here we present the first description of a large-scale VR deployment [n = 75] in an undergraduate human gross anatomy laboratory. This course took a creative and novel approach to solve barriers to learning access imposed by the Covid-19 pandemic and addresses the increasing demand of online human anatomy coursework. The course provided students with a state-of-the-art, interactive gross anatomy laboratory taught synchronously using VR. It was designed with flexibility in mind to accommodate many learners without compromising course rigor and the student learning experience. Data were collected on the effectiveness of the course, including student engagement, performance, and student understanding and retention of anatomical spatial relationships. It was hypothesized that this VR course created similar student outcomes to in-person laboratories, promoted student engagement, and improved student knowledge acquisition and retention of anatomical spatial relationships when compared to 2D methods.

This study was guided by the following research questions:

1. Does this online course provide a comparable alternative to in-person cadaveric laboratories?
2. Does the use of VR promote student engagement with peers, instructors, and content?
3. Does the use of VR improve student knowledge acquisition and retention of anatomical spatial relationships?

2.2 MATERIALS AND METHODS

2.2.1 Course Structure and Grading

This study was conducted in an eight-week, 75 person undergraduate-level online human anatomy course at CSU. This five-credit hour course consisted of the following each week: six asynchronous 50-minute lectures, two virtual synchronous 30-minute recitation periods, and two one-hour synchronous virtual human cadaver laboratory periods immediately following recitation. Students spent a total of 9 hours per week of mandatory course time, for a total of 72 required hours throughout the semester. Teaching assistants (TAs), VR technical support staff, instructors, and professors were present during the recitation and laboratory times.

During recitation periods, half of the students attended an instructor-led session via ZOOM video conferencing platform (Eric Yuan, San Jose, California), in which the instructor reviewed relevant anatomy corresponding to the week's material using the provided BanAnatomy software. The other half attended these "relevant anatomy sessions" with an instructor using the provided VR software. Recitation group assignment (ZOOM vs VR) alternated each unit to provide all students equal access to both instructional methods for the recitation sessions.

Following each recitation, all students completed an online recitation quiz before beginning their synchronous virtual laboratory sessions. Recitation quizzes were designed to assess student understanding of anatomical spatial relationships and were based on the material presented in the previous recitation period. Questions followed the Application level of Bloom's taxonomy level, asking students to apply their understanding of directional terms, anatomical structures, and spatial relationships to identify the relationship of two structures.

During virtual laboratory sessions students engaged in small group work, collaborating to identify and understand relevant structures on an artist-rendered cadaver. Student groups were each assigned to a "VR breakout room," which TAs, instructors, and professors were able to join to answer questions, quiz groups, and facilitate learning. Laboratory sessions were designed to be student-led and self-directed, requiring students to use a provided laboratory guide to identify relevant structures on the virtual cadaver. Technical support staff was available for software questions and technical issues during each laboratory session. To bolster individualized student learning of laboratory content, TA's additionally facilitated daily "open laboratory hours" each week, in which students could meet with their groups and TA's to ask questions and study together. Students were also able to access the virtual cadaver in both BanAnatomy (iPad program) and BananaVision (VR program) at any time outside of formal laboratory instruction hours for independent study and group study. All students received training on how to use the software before and during the first week of the course consisting of in-house built demonstration videos and practice tasks. All faculty and staff were already familiar with the software.

The course was divided regionally into four separate units (Units 1-4), organized chronologically as follows: lower limb (LL); thorax, abdomen and pelvis (TAP); head and neck (H&N); and upper limb (UL). Each unit contained six laboratory periods and approximately twelve lectures. Grading of this course included 200 points from four online unit lecture examinations, 200 points from four online laboratory examinations, eleven online relevant anatomy assignments (25 points), and twelve online recitation assignments (25 points). In addition, extra credit opportunities were present. This course followed an A, B, C, D, F grading scale, with an A greater than 90%, B greater than 80%, C greater than 70%, D greater than 60%, and F below 60%.

2.2.2 BananaVision and BanAnatomy Program

All registered students received an HP Omen Laptop 17t Gaming (3AW55AV_1, Hewlett-Packard Company, Palo Alto, California, USA), a Samsung Odyssey+ head mounted display (HMD) with two controllers (XE800ZBA-HC1US, Samsung, Seoul, South Korea) with pre-installed software one week prior to the start of the course.

This course used an in-house developed BananaVision software, a networked, multiuser tool that leverages cutting-edge VR technology to investigate data in 3D (Figure 2.1, A-D). This in-house developed, multiplayer software allows groups of students to collaborate around the same virtual entity at the same time, while the instructor can join any group's virtual room in real time. Students can dissect a virtual cadaver, create cross-sectional images and explore a variety of volumized medical imaging. It provides users with easy access to explore structural relationships in a more meaningful way in the context of scientific and medical imaging data. Furthermore, this program has implications that reach far beyond the classroom. It permits scientists and clinician's new ways to collaborate and communicate with each other as well as with patients with opportunities for personalized medicine. The benefits of using an in-house developed program were the immediate adjustment of content and implementation of personalized

In addition, the in-house developed BanAnatomy software enables students in this course to study the same anatomical models used in BananaVision without the use of controllers and headsets (Figure 2.1, E-F). This software features a three-dimensional cadaver that students can view and manipulate on a 2D screen. All students were able to access the software during synchronous class time as well as at their own leisure.

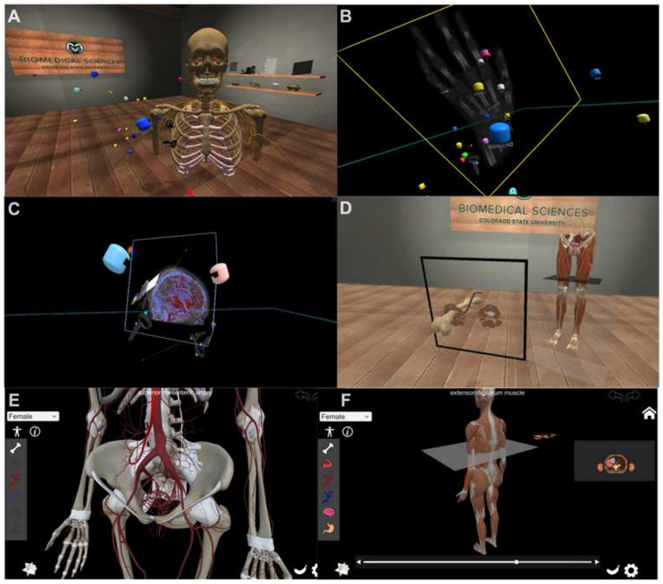

Figure 2.1: BananaVision and BanAnatomy Software. An overview of BananaVision (VR) and BanAnatomy (iPad) software functions. A. Instructor collaborating with several students on the virtual cadaver in BananaVision. B. Instructor collaborating with several students on volumetric medical imaging in the volumetric scene in BananaVision. C. Cross section function in the volumetric scene of BananaVision. D. Cross section function of the virtual cadaver. E. Isolated arterial system in BanAnatomy. F. Cross section function in BanAnatomy.

2.2.3 Laboratory and Lecture Examinations

Examinations were administered every other week in this course, corresponding with the four units. Laboratory examinations were held in an online format of 50 questions and were composed primarily of virtual cadaver identification questions, with several bony landmark identification and critical thinking questions (Appendix A). Critical thinking questions focused on integrating lecture content, such as innervation, attachment, and anatomical function. All questions were open-answered and composed of screenshots of the BanAnatomy program administered via the Canvas learning management system (Instructure Inc, Salt Lake City, Utah, USA). The examination questions were comparable in difficulty level to previous semesters; identification questions followed the Remembering order of Bloom's Taxonomy, while critical thinking questions were categorized as the Application order.

Lecture examinations were administered on the Canvas learning management system as well. These examinations consisted of multiple-choice questions over content covered in lecture and the laboratory (Appendix B). The majority of lecture examination questions were first-order questions (Remembering and Understanding Bloom's Taxonomy Levels), with a few higher order questions requiring critical thinking skills.

2.2.4 Participants

All students enrolled in the online undergraduate human anatomy class at CSU in summer of 2020 were considered as participants for this study. Participant ages ranged from 20 to 30 years old and students were primarily enrolled in undergraduate programs (91%, n = 50, Table 2.1) in Biology/Biomedical Sciences, Health and Exercise Sciences, or Human Development and Family Studies. Only five students were enrolled in a graduate level program (9%, n = 5).

All students were offered extra credit in the course for completing quizzes and surveys, regardless of study participation. In the administered pre-survey, students were additionally given the option to consent to use of survey and quiz results for research purposes.

Table 2.1: Participant Majors Enrolled in Human Anatomy Course. Students had to indicate the pre-survey which major they were enrolled in [n =55].

	Number of Participants
Health and Exercise Sciences	17 [31%]
Biology/Biomedical Sciences	14 [25%]
Human Development and Family Studies	9 [16%]

Anthropology	3 [5%]
Neuroscience	3 [5%]
Biochemistry	2 [4%]
Other	7 [13%]

2.2.5 Data Collection

Comparison of student examination scores was used to evaluate the effectiveness of the virtual course, and it was hypothesized that VR would serve as an effective method of teaching anatomy. Examination scores from the online cohort were collected and compared to a F2F section of the course from a previous semester (Summer 2019). Both sections of the course covered approximately the same material, and exams were of a similar difficulty and structure. It was therefore concluded that the two sections were appropriate for comparison. Of note, the 2019 F2F section utilized prosected cadavers during laboratory sessions while the 2020 online cohort utilized virtual cadavers offered by BanAnatomy and BananaVision. Scores from students who completed all examinations were included in this study, and students who did not complete all examinations were excluded from this portion of the study. Scores were collected retrospectively and anonymously.

To assess the role of VR in student knowledge acquisition and retention of anatomical spatial relationships, students completed periodic quizzes following recitations in either ZOOM or VR. The control group used BanAnatomy through ZOOM during recitation, and the experimental group used BananaVision (referred to as the VR group). Quizzes were administered immediately following the first recitation of each unit and tested student knowledge on spatial relationships in that anatomical region. All students were asked to complete an identical pre-quiz before recitations to ensure both groups began with a similar baseline knowledge. Students completed an immediate post-quiz following recitation, and a retention-quiz seven days after the recitation in order to measure student knowledge acquisition and retention in anatomical spatial relationships (Figure 2.2). Due to the short duration of the course, the upper limb post-quiz was administered 3-5 days after the immediate post-quiz. Quizzes contained ten questions on structural relationships and students identified the appropriate answer using a drop-down menu. All three quizzes contained identical questions. In order to control for the testing effect, answers were not visible upon completion and focused on using anatomical terms to describe relationships instead of retrieval of factual knowledge. An example quiz is demonstrated in Table 2.2.

To assess student perceptions of utilizing VR in the classroom, a pre-survey and post-survey was administered in the beginning and at the end of the course via CSU's online Canvas learning management system (Appendix C and D, respectively). Data were collected from all students who completed both surveys and consented to participate in the study. Pre-survey questions included what major and year they were enrolled in, what their previous experiences were with VR, what hesitations they had in using VR in an educational setting, and perceived confidence in visualizing objects in 3D. The post-survey focused on level of program usage, positive and negative program feedback, perceived frequency and comfort of VR interactions, perceived confidence in visualizing objects in 3D, and improvement suggestions.

Table 2.2: Example Head and Neck Quiz. Example quiz within the Head and Neck section. Students chose the correct answer via a drop-down menu. Correct answers are highlighted in red.

The sternocleidomastoid muscle is (**superficial**/**deep**) to the sternohyoid muscle. The sternocleidomastoid muscle attaches on the (**medial**/**lateral**) aspect of the clavicle. The other attachment point, the mastoid process, is (**anterior**/**posterior**) to the external ear.
The external jugular vein runs (**superficial**/**deep**) to the sternocleidomastoid muscle and the internal jugular vein runs (**superficial**/**deep**) to the sternocleidomastoid muscle. The internal jugular vein runs (**medial**/**lateral**) to the external carotid artery.
The trachea is located (**deep**/**superficial**) to the thyroid gland, and (**anterior**/**posterior**) to the esophagus.
The vagus nerve runs (**anterior**/**posterior**) to the sternocleidomastoid muscle and (**medial**/**lateral**) to the common carotid artery.

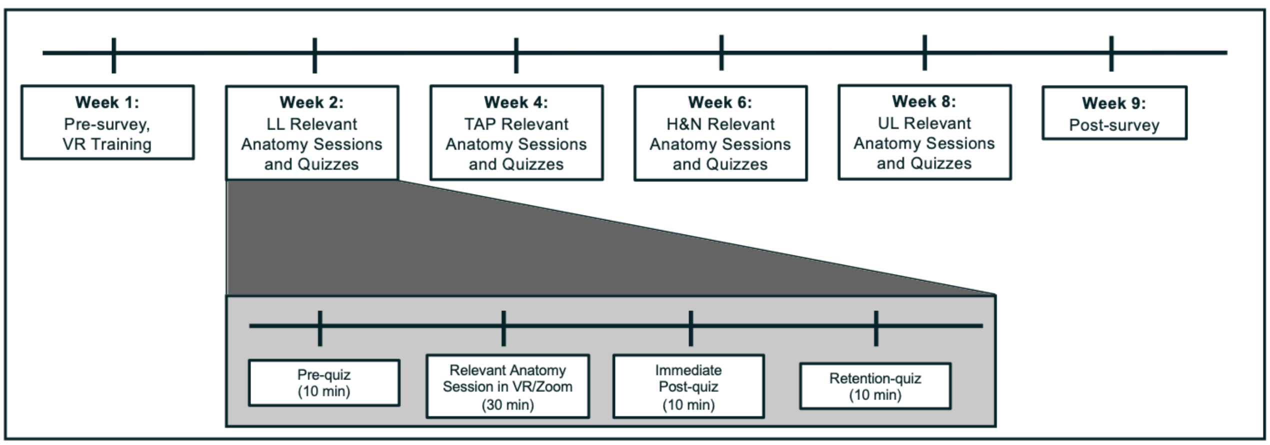

Figure 2.2: Visual for Methods. The study was composed of administration of a pre-survey and a post-survey for qualitative data collection on student perceptions of the VR anatomy laboratory. Quantitative data on student learning was assessed using quizzes to assess understanding of anatomical spatial relationships. Each pre-quiz was administered one day prior to the relevant anatomy sessions to assess baseline knowledge. The post-quiz was administered immediately following the sessions, and a retention quiz was administered 7 days after the post-quiz. Due to time constraints of the course, the UL retention quiz was administered 5 days after the post-quiz. Quizzes were conducted at the beginning of each of four anatomy units (LL = Lower Limb, TAP = Thorax, Abdomen, Pelvis, H&N = Head and Neck and UL = Upper Limb) throughout the semester to evaluate longitudinal changes.

2.2.6 Data Analysis

Student unit examination scores from 2019 and 2020 were analyzed using an unpaired t-test; examination scores from all units followed an approximate normal distribution, indicating that a parametric analysis was appropriate. Quiz scores (pre-, immediate post-, and retention-quiz) within each group (control or VR group) were compared using a repeated measures one-way analysis of variance (ANOVA), followed by a post-hoc Tukey test. An ANOVA was chosen as quiz scores followed an approximate normal distribution. Quiz scores between the groups were compared using an unpaired t-test. Statistical significance was set at 0.05 level. F-tests were performed to test for equal and unequal variances during the analyses and percent values of student numbers were rounded to the next integer. These methods were used to determine whether these populations were statistically different from each other. All quantitative data was analyzed using R Project (The R Foundation for Statistical Computing, Vienna, Austria) and GraphPad Prism 9, version 8.4.3 for Mac, (GraphPad Software, La Jolla, CA, USA).

After qualitative survey responses were collected, each open-answer question was reviewed individually, and themes were identified by individual researcher personnel using an open coding scheme. These preliminary themes were then reviewed during the phase of axial coding as repetitions of codes were searched and connected. Finally, those merged codes assisted in answering the research questions.

2.2.7 Positionality and Trustworthiness

To enhance the quality and trustworthiness of the data, the coding of the qualitative data were performed by both primary researchers independently and then analyzed upon comparison. The positionality of the primary researchers added to the trustworthiness as they both were teaching aids in the summer course and had been working as TAs for multiple years. Both had an extensive background in human anatomy and cadaveric dissection that might have contributed to the formation of rapport and trust with the students. Additionally, both have worked with teaching staff to build the course curriculum and refine the VR program. This experience may also negatively influence the trustworthiness of the study as such work may be seen as a possibility for bias and choice of themes during the study.

2.3 RESULTS

The findings of this study were based on survey responses, quiz scores, and student examination scores organized by their respective research questions.

2.3.1 A Comparable Alternative to F2F Instruction

To answer this research question, data on students' examination scores from the F2F class of summer 2019 were compared to students' examination scores from this online course. Additionally, students' perceptions of what benefits they saw in utilizing VR and how comfortable they felt in visualizing anatomical structures in three dimensions were collected.

2.3.1.1 Previous Semester Comparison

Overall, students in F2F and virtual courses performed equally well on unit examinations, but the mean score of virtual students was significantly higher when composite means were compared. Comparing student examination scores from this study with the students enrolled in the F2F class in summer of 2019 (Table 2.3), statistical analysis revealed no difference between the mean scores within the Lower Limb (Unit 1; $t(284) = 1.01$, $p = 0.31$), Head and Neck (Unit 3; $t(284) = 0.58$, $p = 0.56$), and Upper Limb unit (Unit 4; $t(284) = 1.94$, $p = 0.05$). Within Unit 2 (Thorax, Abdomen, Pelvis), mean examination scores from students enrolled in the online course was higher than the mean of those enrolled in the traditional course ($t(284) = 2.34$, $p = 0.02$).

Table 2.3: Statistical Analysis Comparing 2019 and 2020 Examination Scores. Results indicating number of observations (n), mean, 95% confidence interval (CI), t statistic (t Stat), R squared value, degrees of freedom (df), p-value (p), and whether the null hypothesis is accepted or rejected. TAP = Thorax, Abdomen, and Pelvis.

Unit	Year	n	Mean	95% CI	t Stat	R squared	df	*p*	Decision
1: Lower Limb	2019	150	78.4	-1.54,4.77	1.007	0.003559	284	0.3147	Accept
	2020	136	80.01						
2: TAP	2019	150	80.59	0.533,6.12	2.344	0.01898	284	0.0198	Reject
	2020	136	83.91						
3: Head and Neck	2019	150	78.04	-2.62,4.83	0.5835	0.001197	284	0.56	Accept
	2020	136	79.15						
4: Upper Limb	2019	150	83.3	-0.043,5.44	1.937	0.01304	284	0.0537	Accept
	2020	136	86						

Comparing the total mean examination score over all units of both courses an unpaired t-test analysis assuming unequal variances indicated that the online cohort performed significantly better ($t(1142) = 2.71$, $p < 0.01$). The mean for 2020 was 82.27% (n = 544) and 80.08% for 2019 (n = 600).

2.3.1.2 Benefits

When asked in the post-survey (n = 55) how VR assisted in learning anatomy in a multi-select question (Figure 2.3), the majority of students indicated that VR promoted understanding of spatial relationships (87%, n = 48) and understanding of anatomical system (80%, n = 44). Students also reported that VR enhanced their recall of anatomical structures (69%, n = 38), understanding of anatomical images in a book (51%, n = 28), ability to use anatomical knowledge to solve a problem (36%, n = 20), and the functions of anatomical structures (35%, n = 19).

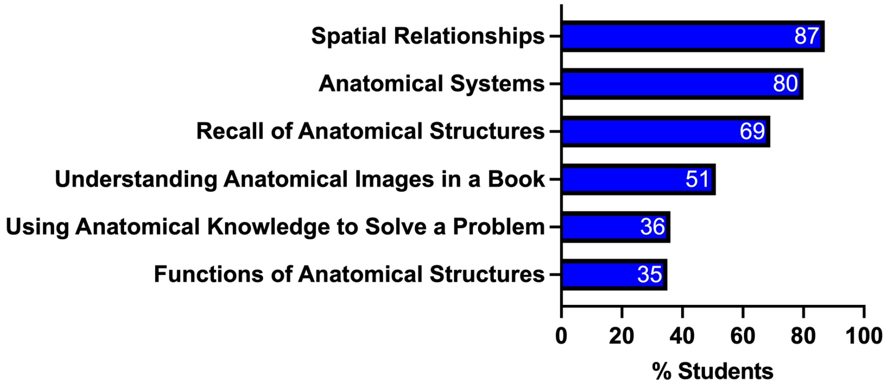

Figure 2.3: VR Assistance in Learning Anatomy. Students indicated in a post-survey multi-select question on how VR assisted their learning in anatomy.

2.3.1.3 Confidence in Visualizing in 3D

Students reported an increase in confidence when visualizing in 3D (Figure 2.4; n = 55). Students increased in their mean confidence between the pre and post survey (3.07 ± 0.88 vs 3.41 ± 0.98, $p < 0.01$). At the beginning of the course, 33% of students (n = 18) were confident or very confident in their ability to visualize in 3D. Some students were somewhat confident (45%, n = 25), while 22% (n = 12) reported feeling slightly confident or not confident at all in their visualizations. The post survey indicated that students felt more confident in their ability to visualize in 3D; 56% (n = 31) felt either confident or very confident, 27% (n = 15) felt somewhat confident and 16% (n = 9) felt either slightly confident or not confident at all.

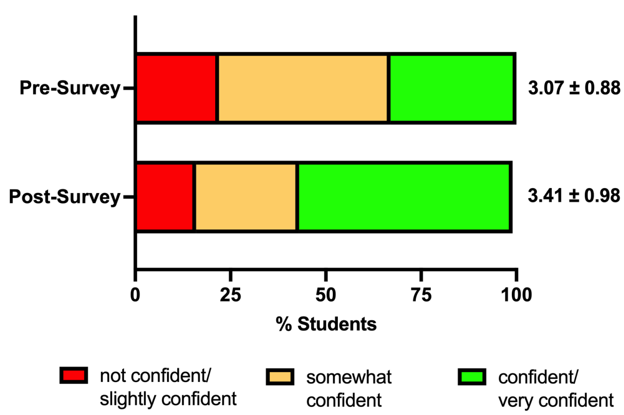

Figure 2.4: Confidence in Visualizing in 3D. Students were asked in the pre- and the post-survey how comfortable they felt in visualizing anatomical structures in 3D on a 5-point Likert scale. Students increased in their mean confidence between the pre and post survey (3.07±0.88 vs 3.41±0.98).

2.3.2 VR and Student Engagement

To answer this research question, positive and negative program feedback was collected in the post-survey. Furthermore, student responses on frequency and comfort level of virtual interactions were analyzed. Students were additionally asked if they would enroll in a VR course again to further measure engagement.

2.3.2.1 Student Perceptions of Virtual Reality

Primary themes identified from student positive feedback included *the immersive and interactive nature of the program*, the *convenience of 24/7 lab access*, and the *detail of the virtual cadaver*. Notable themes identified from negative feedback focused on *student side effects* and *technical difficulties.* Out of 55 students completing the post-survey, 51 students provided extensive feedback on likes/dislikes of BananaVision in response to open-ended post-survey questions (Figure 2.5A). Primary themes included the ability to manipulate the virtual cadaver (49%, n = 25) and the immersive nature of the program (38%, n = 21). Additional positive themes included the convenience of 24/7 "lab" access, granted by the accessibility of their home VR computers (27%, n = 14). In addition, students liked the detail of the virtual cadaver (23%, n = 12), ability to isolate anatomical systems in VR (to selectively view muscular, arterial/venous, nervous, digestive, etc.) (14%, n = 7), the ability to dissect structures (14%, n = 7), and other varied aspects (8%, n = 4).

On the other hand (Figure 2.5B), students notably experienced side effects such as the HMD being uncomfortable after extended use (>1 hour) (32%, n = 18), and disliked the learning curve associated with the program (20%, n = 11). Some students experienced technical difficulties or connectivity issues (16%, n = 9). Four students (7%) mentioned the inconvenience of wearing a HMD during instructor-led sessions, as they were unable to simultaneously take notes. Few students (< 10%) complained of lack of haptic feedback and uncomfortable fitting of the head-mounted display (HMD).

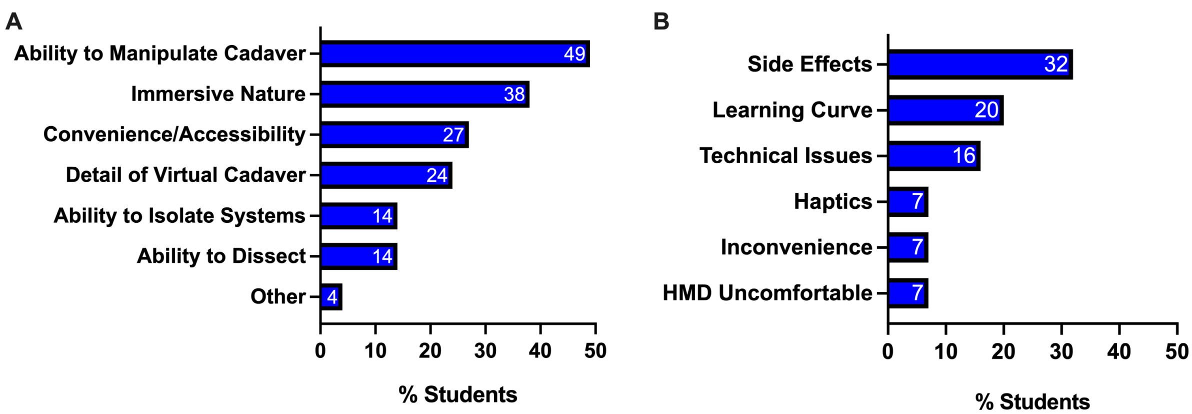

Figure 2.5: Feedback on VR Program. A. Positive feedback of BananaVision. B. Negative Feedback of BananaVision. Students provided positive and negative feedback on the VR program in a post-survey essay style question. Responses were coded using an open coding scheme to identify primary themes. Prevalence of each theme is visualized by percentage.

2.3.2.2 Frequency and Comfort Level of Virtual Interactions

Overall, students felt that they had ample opportunity for interpersonal interactions in VR, and felt comfortable during these interactions. In the post-survey, students were asked to rate the frequency at which they were provided the opportunity to interact with TAs, peers, the content, and ability to ask questions (Figure 2.6A; n = 55). Students were further asked to rate their comfort of virtual interaction with TAs, peers, content, and ability to ask questions (Figure 2.6B, n = 55).

Both questions were rated on a 5-point Likert scale. Overall, a majority of students felt that they either often or very often had the opportunity to interact with TAs (65%, n = 36), peers (58%, n = 32), the content (91%, n = 50), and ask questions (67%, n = 37). Some students indicated that they very rarely to rarely had interaction opportunities with TAs (13%, n = 7), peers (22%, n = 12), the content (2%, n = 1), and asking questions (4%, n = 2).

In regard to the comfort level of those virtual interactions, students indicated that they felt either comfortable or very comfortable interacting with TAs (65%, n = 36), peers (60%, n = 33), the content (67%, n = 37), and asking questions (58%, n = 32). A small number of students mentioned that they felt uncomfortable or very uncomfortable interacting with TAs (9%, n = 5), peers (16%, n = 9), the content (11%, n = 6), and asking questions (16%, n = 9).

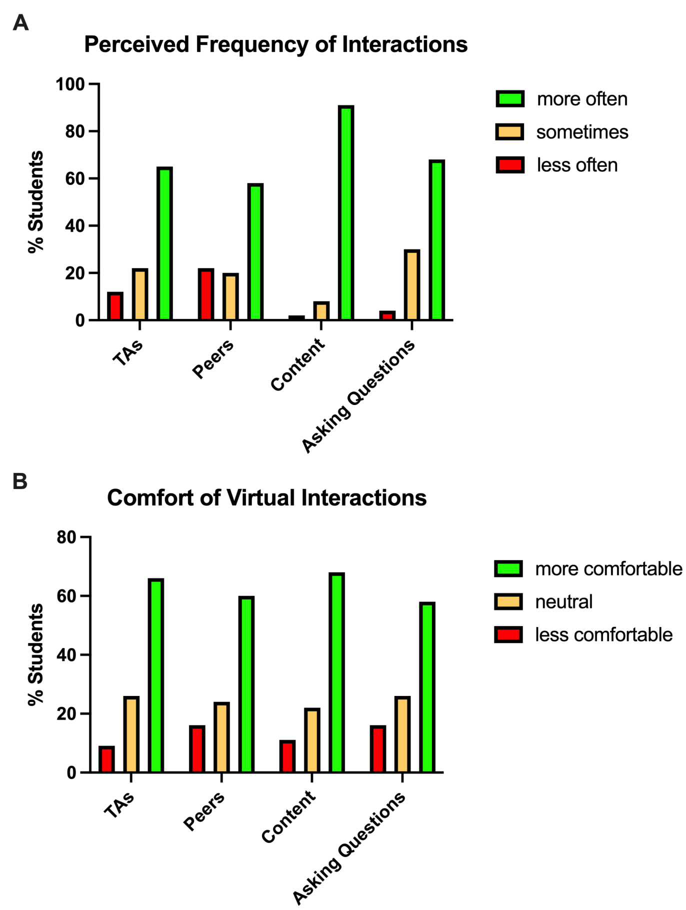

Figure 2.6: Perceived Frequency and Comfort of Interaction Opportunities. A. Perceived Frequency of Virtual Interactions. B. Comfort of Virtual Interactions. Students indicated in post-survey Likert scale questions their perceived frequency and comfort of virtual interactions on a 5-point Likert scale.

2.3.2.3 Enrollment

The majority of students perceived VR as useful to their learning and indicated that they would consider enrolling in a VR-based course in the future. Analysis indicated that 75% of students saw utility in utilization of VR in learning anatomy (n = 41), with 67% of students (n = 37) choosing to enroll in a fully virtual course again (Yes, n = 26; Yes, in-person component preferred, n = 11) and four students (7%) preferring VR use as a supplemental tool only. While 25% of students (n = 14) indicated that they would not take a VR course again, six of these students (10% of class) cited side effects as their primary reason. Seven students (13%) indicated that they would not re-enroll in a VR course again because it did not match their learning preferences (preferred physical classroom experience and note-taking ability were most commonly cited).

2.3.3 VR and Student Knowledge

To answer this research question, student quiz scores (pre-, immediate post-, and retention-quiz) were compared and categorized according to the technology the students used during recitation. Overall, the data provided mixed results in terms of knowledge acquisition and retention of anatomical spatial relationships.

In Unit 1 (LL), control student quiz scores increased between both the pre-quiz and immediate post-quiz ($p = 0.0169$), and between the pre-quiz and retention quiz ($p < 0.01$), with no differences observed between the immediate-post-quiz and retention quiz ($F(2,13) = 9.135$, $p < 0.01$, Figure 2.7). VR student quiz scores increased between the pre-quiz and immediate post-quiz ($p = 0.0214$), with no difference between mean scores between the post-quiz and retention quiz ($F(2,16) = 3.572$, $p = 0.0473$). The control group and VR group LL quiz scores did not significantly vary from each other.

In Unit 2 (TAP), control student quiz scores increased between the pre-quiz and immediate post-quiz ($p < 0.01$) and between the pre-quiz and retention-quiz ($p < 0.01$), with no differences observed between the post-quiz and retention quiz ($F(2,15) = 15.69$, $p < 0.01$ Figure 2.7). There were no differences between the pre-quiz, post-quiz and retention quizzes of the VR group ($F(2,6) = 0.06667$, $p = 0.9296$).

In Unit 3, (H&N), there was no statistically significant variation among the conditions for the control group, $F(2,17) = 1.075$, $p = 0.3396$ (Figure 7), the VR group, $F(2,10) = 1.023$, $p = 0.3608$, or between the two groups within each quiz.

In Unit 4 (UL), control student quiz scores increased between both the pre-quiz and immediate post-quiz ($p < 0.01$), and between the pre-quiz and retention quiz ($p = 0.0474$), with no differences observed between the immediate-post-quiz and retention quiz ($F(2,15) = 7.369$, $p < 0.01$, Figure 2.7). VR student mean quiz scores also increased between the pre-quiz and retention quiz ($p = 0.0197$), with no differences observed between the mean scores of the pre-quiz and the immediate post-quiz scores nor between the immediate post-quiz and the retention-quiz. VR students scored significantly higher on the retention quiz compared to the control group ($t(22.62) = 4.012$, $p = 0.0006$).

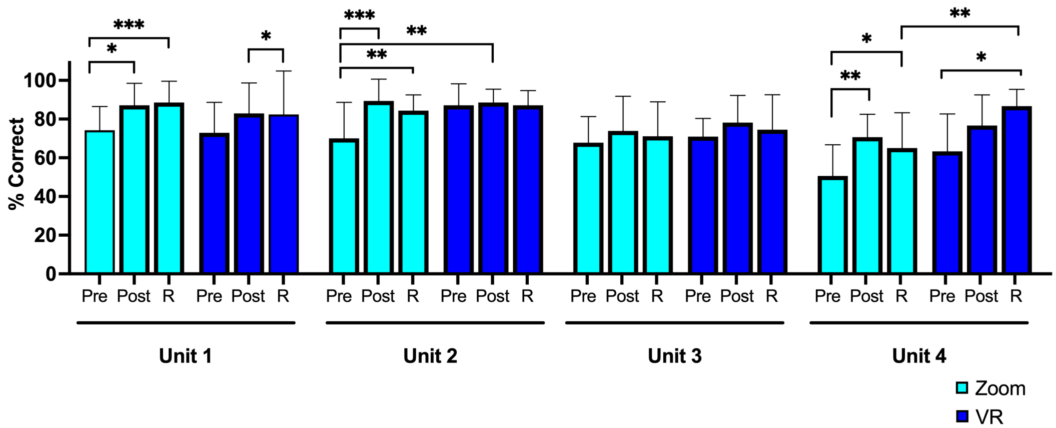

*Figure 2.7: Retention within Lower Limb, TAP, Head and Neck and Upper Limb. Understanding of anatomical spatial relationships between the pre-quiz, post-quiz, and the retention quiz of students using either Virtual Reality or Zoom. Pre = Pre-Quiz. Post = Post-Quiz. R = Retention-Quiz. Statistical significance and power indicated by * with alpha = 0.05. * Error bars = Mean with SD.*

2.4 DISCUSSION

2.4.1 A Comparable Alternative to F2F Instruction

Several studies have shown that if online modules are effectively implemented, students demonstrate equivalent knowledge acquisition when compared to F2F instruction (Attardi & Rogers, 2015; Brinson, 2015; Dyrberg et al., 2017; Penn & Ramnarain, 2019). Studies utilizing VR in human anatomy and neuroanatomy courses have reported no difference in quiz scores when compared to F2F instruction (Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017). Conversely in this study, students in the remote course utilizing VR outperformed those in previous F2F offerings of the same course, shown by a higher total averaged mean examination score in 2020. Students enrolled in 2020 acquired equivalent or greater anatomical knowledge compared to 2019, suggesting that this online course provided a successful and comparable alternative to in-person cadaveric laboratories. The instructors who taught the F2F class in 2019 remained the same for this online course and focused on keeping a similar difficulty level of questions posed during the online examinations. Nevertheless, it is important to note that students enrolled in 2019 were tested on anatomical structures on cadavers whereas the students enrolled in this online course were tested on anatomical structures on the control BanAnatomy software.

Most students indicated that VR promoted their understanding of spatial relationships (87%) and the understanding of anatomical systems (80%; Figure 2.3) as stated by one student, "I was most successful in understanding material when I used the VR program. I am an extremely kinesthetic learner, and it's challenging to grasp and retain knowledge without hands-on experience. Out of all of the resources, VR came the closest to fulfilling my learning style". Furthermore, students reported an increase in confidence when visualizing in 3D at the end of the course (Figure 2.4). As stated in the literature, students often struggle to visualize anatomical spatial relationships in 3D and several studies have established a positive correlation between spatial abilities and student outcomes (Estevez et al., 2010; Guillot et al., 2007; Langlois et al., 2017; Lufter et al., 2012;). Utilization of VR as a supplemental tool in human anatomy allows students to visualize and spatially interact with anatomical structures in true 3D. The unique perspectives afforded by VR may assist students in visualization of structures in three dimensions, but further research should be conducted in this area. This increase in confidence in visualizing structures in 3D adds to the existing literature as there is mixed evidence on the relationship between VR usage and understanding and retention of anatomical spatial relationships (Moro et al., 2017; Ekstrand et al., 2018). This, paired with the reported data of high engagement, provides a strong argument for the use of VR as a tool in distance education as an effective alternative to in-person cadaveric laboratories.

2.4.2 VR and Student Engagement

As identified in previous studies, some online anatomy laboratories struggle to maintain a high level of student engagement and satisfaction (Attardi et al., 2018; Mathiowetz et al., 2016). The virtual course piloted in this study showed a high level of student engagement and satisfaction. Engagement was determined utilizing data on student-reported likes of the program and course, as well as student perceived opportunities of and comfort of virtual interactions. Student-reported likes focused on elements of the VR program that were unique to their virtual learning environment; that is, elements the students most appreciated could not be easily replicated in the traditional cadaveric laboratory. Unique program elements mentioned included the ability to interact with data in true 3D, isolate systems, dissect, and the detail of the virtual cadaver, in addition to broader likes that included convenience, accessibility, and the immersive nature of VR. The extensive positive feedback of the program's design, flexibility, and components suggest a high level of both student engagement and satisfaction. Quotations from students further demonstrate high engagement utilizing BananaVision such as "*Being able to immerse ourselves within a human body in VR allow[ed] us to look [at] the human bodies in ways previous classes never have before. It was new and exciting",* "Very engaging and cool way to learn the structures. I like how user friendly the VR is and the ability to raise hands and ask questions", and "*I think it was super beneficial to have VR right at my fingertips all the time. Instead of having specific times when [the] lab[oratory] would be open I could get on VR any time I wanted throughout the day to study - I loved having the opportunity to do that!"*

The majority of students further reported having frequent opportunities to interact with their TAs, peers, and course content (Figure 2.6). A large majority of students reported a high level of comfort in these interactions, suggesting that the virtual environment provided a positive interaction experience. The combination of high comfort and frequency of interaction opportunities also suggests a high level of engagement. This conclusion is further corroborated by a high number of student-perceived benefits and extensive self-reported positive program feedback.

Based on student-reported benefits, it is significant that the most-liked program elements were those unique to their virtual learning environment. For example, the ability to extensively manipulate and explore the virtual cadaver was the most liked feature of the program, and this element would not have been available to students in a traditional laboratory setting. This is additionally true for the ability to isolate anatomical systems as desired. As stated by one student, "*I … liked that you could change the perspective [and size of the cadaver] in order to gain a more complete understanding about how structures relate to each other"*. In the traditional cadaveric laboratory, students may be hindered by limited perspectives on hard-to-see structures; in the VR program, students are able to dissect to their desired view, walk inside and along structures, and view from any angle and/or size. This program feature was especially appreciated by the students, exemplified by this student observation:

> *I really enjoy[ed] the VR since there are aspects that you would not be able to do with an actual cadaver. For example, when learning the bony landmarks of the skull you can go inside it and clearly see where the bony landmarks were as well as choosing to add different structures such as nerves to see where they go and gain a better understanding how things are spatially arranged.*

The utilization of VR in this course provided unique benefits for the students to interact with and explore anatomical content in novel ways. This further supports the conclusions of existing literature, with students reporting higher motivation and perceived usefulness using VR (Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017) compared to control groups using paper-based study methods. Students additionally enjoyed the high level of accessibility offered by the program, having virtual “lab” access 24/7 (see “Convenience/Accessibility” in Figure 2.5). In previously offered in-person anatomy laboratory sessions, students have struggled to schedule their weeks around limited open-laboratory hours to work with real cadavers outside of designated laboratory sessions. In this virtual course, the program accessibility addressed this issue as stated by one student, “... [the] online environment made the material more accessible and life-like as if we were in the cadaver lab”. Students were able to fit their laboratory sessions in times that fit their already-busy schedules. This, combined with the reported data of 67% of students being interested in enrolling in a fully VR course again and the additional 7% who advocated for using VR as a supplemental tool, provides a strong argument for the use of VR as a tool in distance education. The virtual classroom provided a level of accessibility that caters to the diverse lives of many learners, without compromising learner engagement.

2.4.3 VR and Student Knowledge

In previously reported anatomy laboratories, students have demonstrated equivalent (Stepan et al., 2017) or greater knowledge retention in anatomical content (Moro et al., 2017) when using VR compared to paper-based control groups. This study corroborates the existing evidence that VR was comparable to 2D methods in student knowledge retention. Results from the Lower Limb quizzes indicate that the control and VR groups experienced equivalent increases in knowledge acquisition, demonstrated by the difference between the pre-quiz and the immediate post-quiz (Figure 2.7). Additionally, both groups demonstrated equivalent knowledge retention. Comparison of post-quiz and retention-quiz scores revealed no significant differences suggesting that students retained their knowledge of spatial relationships independent of modality used.

Notably, there was a difference in baseline knowledge between groups in TAP, and no knowledge acquisition or retention in either group for the Head and Neck unit (Figure 2.7).

Within the Upper Limb unit of the course, both groups trended towards an increase in knowledge acquisition, with the control group demonstrating a statistically significant increase (Figure 2.7). The use of VR during recitation did not result in a change in knowledge acquisition, but student knowledge increased between the pre- and the retention-quiz. This may indicate that students retained the material learned during recitation but were not able to access the learned information in the immediate post-quiz. The VR group may have also been negatively affected by their inability to take notes while wearing their HMDs. Students learning human anatomy for the first time especially in such a short duration often rely on notes taken during the recitation sessions, potentially providing the control group an unfair advantage. Students in the VR group showed an increase in retention in the Upper Limb unit compared to the control group.

Overall, the mixed data suggest that using VR and BanAnatomy during recitation resulted in equal knowledge acquisition and retention of anatomical spatial relationships. These findings are further supported by the literature as previous studies have shown that students have demonstrated equivalent knowledge acquisition between in-person and online laboratory modules in other subjects (Brinson, 2015; Dyrberg et al., 2017; Pen & Ramnarain, 2019).

2.5 LESSONS LEARNED

During the preparation and throughout the eight-week course, the research team faced several issues regarding the course structure and implementation. Following are the lessons learned:

- Account for hardware delivery delays. The hardware should be ordered in a timely manner to prevent shipping delays and to give the technical team enough time to install the software and prepare for the course.
- Recruit student addresses early. Students do not frequently check their emails, especially during the summer months. Some missed the deadline for submitting physical addresses and thus had to pick up the hardware in person.
- Have a designated technical team. The research team planned on having the team present only during the first two weeks of the course, but problems arose more frequently than expected. Having a designated technical team present during the synchronous section of the course provided the instructors time to focus on their anatomy instruction.
- Integrate the software into the curriculum in various ways. In this course, the VR program was a supplemental tool to learning anatomy (outside mandatory synchronous VR laboratory sessions). Implementing a VR component to the examinations may increase student usage.
- Administer surveys. If student attendance decreases during the synchronous portions of the class, administer a quick online survey in order to address this issue and increase online engagement. In this course, students did not attend some synchronous laboratory sessions due to time conflict (43%), VR side effects such as the HMD being uncomfortable (35%), and technical/connectivity difficulties (35%). VR side effects include dizziness and fatigue and technical difficulties related to audio issues in the beginning of the semester as well as private internet connection problems. The research and technical team were able to address these specific issues.

- Offer extra credit. In this course, extra credit was offered to all students as an incentive for completing the surveys and quizzes. This increased study participation.

2.6 LIMITATIONS

The biggest limitation of this study was that the research team was not able to control students' usage of the control versus the VR program outside of designated laboratory hours, which may have influenced the data. The simultaneous use of the two softwares resulted in a barrier of effectively comparing the two technologies. While designing the curriculum, the research team did not plan to restrict the usage of either program to accommodate individual preferences of the learners. However, in future classes, this should be modified in order to determine which program assisted students the most in terms of knowledge acquisition and retention of anatomical spatial relationships.

Another limitation was that students were not able to take notes when using VR during their recitation session. This may have contributed to the lack of interest attending this part of the curriculum and lack of retention observed in this study. Additionally, even though both faculty members who guided the recitation sessions focused on reviewing the same area using either the control or the VR program, the teaching approach may have differed amongst them and thus could have influenced student learning. In addition, students' perceptions on their confidence of spatial anatomical relationships does not necessarily mean that they actually acquired this skill over the course of the semester. Periodic spatial testing, including mental rotation tests, should be conducted in future studies to increase the power of data collection. Additionally, a measurement of cognitive load will be conducted in future research to examine its effect on the students.

Another limitation of this study is the difference in circumstance of the two courses being compared. In 2019, students took the anatomy course in-person when online teaching methods were not widely incorporated into the curriculum. Students enrolled in 2020 may have been more comfortable with the shift to distance learning during Covid-19. This may have affected the results positively.

The hardware necessary for this course and project was funded through an internal grant at CSU. Currently, the VR program BananaVision is an in-house built software and is only available for students enrolled in this course on the associated computers. This one-time investment on the hardware has been carried forward to support the increased online learning demand due to Covid-19 restrictions.

2.7 FUTURE DIRECTIONS

The VR software BananaVision will be further incorporated into the undergraduate and graduate human anatomy curriculum. In this study, the VR program was used as a supplemental way of learning the material and was not specifically tested on examinations. This may have contributed to limited usage by some students. Furthermore, observations and comments from teaching assistants in the beginning of the course indicated that some students decided not to use the VR program when they faced technical difficulties or discomfort. Based on this feedback, the technical support team was continuously present in all laboratories and responsive to issues in real-time. This will need to be an integral part of future classes to address student issues and concerns in a timely manner to increase VR usage. It is further important to acknowledge that the use of VR in an educational setting was completely new technology to some students whereas using the BanAnatomy program and watching an instructor via Zoom may have been more familiar to them. With the shift to more online learning during Covid-19, students may have felt more comfortable using 2D online teaching methods.

The technical staff have implemented changes to the program based on student feedback in regard to the amount of detail in the dataset, audio issues while using the software, and general logistics of the class. Regarding the steep learning curve, additional student support will be provided by incorporating additional training sessions into the curriculum in future deployments. These will include live tutorial sessions, recorded modules, and live questions and answers office hours. In the future, the research team is interested in investigating the relationship between students' perceived difficulty using the program and amount of time spent learning the program outside of mandatory laboratory sessions. As with any new technology form, VR requires students to engage with and spend time learning how to efficiently operate the program.

In terms of study design, specific questions to gauge student engagement, perceived usefulness, and satisfaction will be created to better quantify their reactions to using VR to learn human anatomy. Additionally, more qualitative data will be collected in future classes to address arising problems with technical issues and/or health concerns.

To enhance the power of the data collection on knowledge acquisition and student retention, this study will be repeated on concurrently run laboratory sections, with one taught in VR and the other in-person. This design will naturally provide a more stable set of controls and will further quantify relationships between VR usage and student knowledge acquisition and retention. Periodic mental rotation tests will be administered to better assess changes in student spatial ability.

2.8 CONCLUSION

This VR-based anatomy course served as a creative solution to barriers imposed by the Covid-19 pandemic. The present study investigated the role of VR in distance education in a large-scale online human anatomy course. Overall, the virtual classroom maintained the rigor of traditional gross anatomy laboratories without negatively impacting student examination scores and provided a high level of accessibility, without compromising learner engagement. Students especially appreciated the unique aspects of the program that were not replicable in an in-person cadaver lab, such as the ability to infinitely scale and isolate anatomical systems on the virtual cadaver. In addition, mixed results showed equivalent retention of anatomical spatial relationships between instruction modalities. This suggests that VR offers unique benefits as a novel instruction tool in human anatomy.

This study contributes to the existing literature on how to effectively incorporate VR into an anatomy curriculum, as it addresses a variety of learners and offers a critical lens for restructuring curricula. Furthermore, it provides valuable information that can be applied to other online classrooms that struggle to hold student engagement, particularly those that are facing challenges posed by Covid-19 restrictions. With medical education likely undergoing a paradigm shift in the next decade, this course may present an important alternative to how anatomical sciences can be taught and practiced effectively in an online learning environment.

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CHAPTER 3 : EXPLORING THE ROLE OF VIRTUAL REALITY IN STEM DISTANCE EDUCATION AND REMOTE OUTREACH OPPORTUNITIES[2]

3.1 INTRODUCTION

Distance education is essential to the infrastructure of modern education. Once viewed as an exclusively alternative form of education, distance education is becoming a mainstream mode of learning with demand continually increasing (Johnson, 2020). Approximately 3.1 million students enrolled in exclusively online coursework at Title IV institutions in 2017, with an additional 3.5 million postsecondary students taking at least one online course (National Center for Education Statistics, 2018). In total, approximately 6.7 million students at post-secondary institutions enrolled in at least one online course in 2017, comprising one third of all university students (Johnson, 2020). Further, the percentage of students enrolling in exclusively online coursework has jumped from 11.3% in 2012 to 15.4% in 2017, demonstrating that demand is and will continue to expand (Ginder et al., 2018; Lederman, 2018).

The term "distance education" refers to the physical spatial and temporal separation of student and instructor, with instruction, learning, communication, and course resources offered through virtual modalities (Anderson &Rivera-Vargas, 2020). Methods include *asynchronous* and *synchronous* delivery, and instructors typically administer more than 80% of content online (Seaman et al., 2011). Synchronous methods include real-time online interactions with instructor and/or peers, and are often offered through online platforms such as ZOOM, Skype, Microsoft Teams, and others (Khan, 2006; Shahabadi & Uplane, 2015). Facilitations vary widely, but can

[2] This chapter is a modified version of *Exploring the Role of Virtual Reality in STEM Distance Education and Remote Outreach Opportunities,* soon to be under review. List of authors: Katelyn E. Brown, Natascha Heise, Carolyn A. Meyer, Jordan Nelson, Chad M. Eitel, Kenneth R. Ivie Jr., Brandon Lowry, John P. Walrond, Tod R. Clapp

include livestreamed lectures, group seminar-style discussions, student presentations, or small-group work. By contrast, asynchronous learning occurs without the constraints of time, relying on engagement tools such as online discussion forums to humanize interactions (Shahabadi & Uplane, 2015).

Prior to the COVID-19 pandemic, distance education was primarily used by learners separated from their institutions by great distances, often in rural locations or hindered by financial constraints (Pregowska et al., 2021). It also enabled remote learning by learners with disabilities that prevented class attendance and helped adult learners balancing education with a full-time job and/or family responsibilities (Pregowska et al., 2021). However, the broad accessibility, affordability, and flexibility of online learning has allowed learners from diverse backgrounds to expand their knowledge and learn something new (Pregowska et al., 2021).

Many inclusive benefits of distance education have been reported, some studies suggest that online learning can increase student-perceived social isolation, feelings of disconnection, boredom, impaired group cohesion, and distraction from learning (Cesari et al., 2021). Online learning can be prone to student distraction via internet advertisement, social media pull and other outlets, and this detraction of focused learning can negatively affect student engagement, attention, and perceived state of flow (Cesari et al., 2021; Pregowska et al., 2021). As the demand for distance education is continually increasing, it is essential to explore virtual pedagogical methods and education modalities that promote learner attention, engagement, and competency in desired skills.

Although there are many effective methods for online classrooms, the hands-on nature of laboratories remain difficult to effectively replicate in an online environment. In physical science, chemistry and biology, course evaluations of a few carefully designed online laboratories have demonstrated equivalent student outcomes and perceptions/attitudes when compared to traditional face-to-face laboratories (Brinson, 2015; Dyrberg, 2017; Penn & Ramnarain, 2019). However, the hands-on laboratories can be more difficult to replicate in an online environment because students are limited in their ability to interact with laboratory materials (Moosvi, et al., 2019; Sivrikaya, 2019).

During the past five years and specifically since COVID-19, virtual reality (VR) has emerged as a novel tool for immersive learning and use in distance education, which may prove especially useful in developing effective virtual laboratories and rural outreach efforts. In contrast to traditional two-dimensional (2D) methods of online instruction, VR allows the learner to be fully immersed in a three-dimensional environment, in which they can interact with and fully explore the data/material. Further, VR enables multiple students to collaborate in a common virtual environment independent of location (Ardiny & Khanmirza, 2018). Previous studies have demonstrated that utilization of VR in anatomy and neuroanatomy classrooms provides intrinsic learning benefits, promoting student motivation, satisfaction, engagement, immersion, and perceived usefulness compared to traditional paper-based study methods (Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017).

In addition, students using VR or augmented reality (AR) have shown equivalent or greater learning outcomes compared to control methods in anatomy, neuroanatomy, physical science, and chemistry, demonstrating that VR does not detract from (and may in fact promote) student performance (Altmeyer et al., 2020; Dunnagan et al., 2020; Moro et al., 2017; Stepan et al., 2017). While the results of these in-person studies are promising, comparatively few studies have explored the role of VR as a tool in distance education. It is unclear how the use of VR in a fully remote environment can benefit the online learner and more research is needed to better quantify the role of VR in the classroom.

The present study aims to fill the gap in the literature and explore the role of VR in distance education. The study assessed the effectiveness of using VR and case-based learning to virtually connect high school students with graduate student mentors to learn human anatomy on a virtual cadaver. It was hypothesized that 1) VR is an effective tool to remotely link graduate student mentors with high school students, promoting student engagement and motivation, and 2) this VR, case-based curriculum promotes skills for student success (i.e., problem solving, spatial ability, communication, and collaborative skills). "Efficacy" was measured by assessing student and mentor engagement, motivation, satisfaction, and comfort between ZOOM and VR modalities. Development of student success skills were evaluated by assessing changes in student critical thinking ability and spatial awareness.

3.2 METHODS

A high school anatomy course was designed that incorporated VR into a case-based curriculum and included virtual meetings with graduate students from Colorado State University. High school students will henceforth be referred to as "students" and CSU graduate students will be referred to as "mentors".

3.2.1 Course Structure and Grading

The 16-week high school course consisted of four regional units: 1) Lower Limb (LL), 2) Thorax/Abdomen/Pelvis (TAP), 3) Head and Neck (H&N), and 4) Upper Limb (UL). Students were grouped with 4-5 peers and assigned a mentor for the entirety of the course. During each unit, each group received a medical case study containing relevant anatomy/pathology to the unit. Students solved their case study and explored the related anatomy with the assistance of their mentor over three weeks, culminating in an oral presentation to their peers. Each student group solved a total of four clinical case studies over the course of the semester, one regional case per unit. Cases differed between each group so the class could learn a broader range of anatomical topics, but cases were determined to be of a similar difficulty by research personnel and experienced anatomy faculty at CSU.

Each unit was split into 4 weeks (Figure 3.1) – week 1, introductory week, weeks 2 + 3 mentor meetup weeks, week 4- presentation week. During weeks 2 and 3, student groups met remotely with graduate mentors in either ZOOM or VR (alternating each unit for equal access) to work on their case studies.

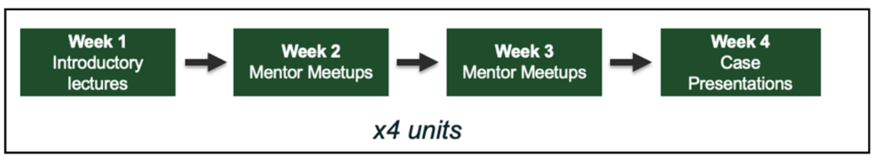

Figure 3.1: Unit Outline. During each unit, students began with an introductory week, followed by two weeks to meet with their mentor and solve their case study. Student groups gave oral case presentations during the last week of each of the four units, Lower Limb (LL), Thorax, Abdomen, Pelvis (TAP), Head and Neck (H&N) and Upper Limb (UL). Students met with mentors in either ZOOM or VR, depending on which modality they were assigned to in each unit.

Mentors participated in a training program to learn effective mentorship skills, approaches for facilitating case studies, and tips for teaching. Mentors were required to solve case studies prior to interactions with their assigned student groups and provided feedback to each other's teaching notes. Mentors were additionally required to attend a monthly check in meeting to discuss their experiences during each unit, and to share their advice with each other.

COVID-19 accommodations were taken under consideration while implementing this course based on the school's requirements.

3.2.2 BananaVision and BanAnatomy

This course utilized an in-house developed VR software called BananaVision, which allows the user to study human anatomy in true immersive 3D on a model cadaver and using volumetric medical imaging (CT/MRI imaging). Using controllers to interact with and move through the environment, users can infinitely scale the model cadaver, dissect structures away, or isolate anatomical and regional systems (musculoskeletal, cardiovascular, lower limb, head and neck, etc.). Additionally, users can create cross sectional images of any section or plane of the body, deepening their understanding of anatomical structural relationships. Controllers are used to interact with the environment and real-time audio provides a realistic "in-person" feel. BananaVision is a multi-user immersive program and has remote connection capabilities that allow users to collaborate in a common virtual environment independent of distance (Figure 3.2).

Students meeting in ZOOM during a given unit utilized an iPad-based version of BananaVision called BanAnatomy, which included the same model data that students can explore without the use of a headset and controllers.

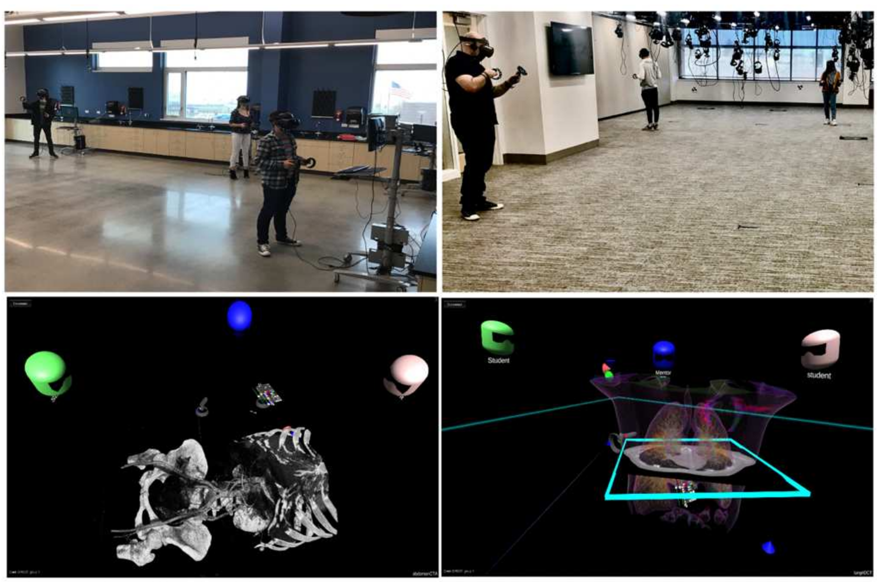

Figure 3.2: BananaVision. High school students (top left) and graduate mentors (top right) separated by 50 miles remotely connect in common virtual space (bottom) to study human anatomy through case-based learning.

3.2.3 Participants

Students from a rural high school biomedical science program were recruited for this study (n=18). Students were in their third year of high school and had previously taken an introductory anatomy and physiology course at their school as part of their program. All students were provided written consent from parents or guardians before study participation was granted (IRB: #2818).

Mentors were recruited from a cohort of graduate students in the Department of Biomedical Sciences at Colorado State University (n=12). Mentors were selected based on their performance in previous semester cadaveric dissection courses and based on their performance in an associated advanced anatomy course which featured case studies and formal presentations.

3.2.4 Data Collection and Analysis

3.2.4.1 Student and Mentor Perceptions

Students were asked to complete a printed pre-survey and post-survey at the beginning and end of the semester, respectively (Appendix E). The surveys were not linked and were analyzed independently of each other. The pre-survey focused on demographic questions as well as previous experience with VR and excitements/hesitations of using VR in the classroom. A post-survey was used to measure perceived participant satisfaction, motivation, comfort, and engagement between ZOOM and VR meetings. These Likert questions were treated as continuous data, as there were at least 5 categories. Likert scale data for both students and mentors were analyzed using the Wilcoxon Signed Rank (Paired) Test. This test was selected as data was not normally distributed, violating an assumption for an unpaired t-test. Open ended response questions to post-survey questions were analyzed using an open coding scheme by two independent analyzers. Themes were then compared and finalized as a team. These analyses were performed for both student and mentor surveys.

Students additionally completed focus group interviews at the end of the semester (Appendix F). Students were split into three focus groups of 6 (n=18), and questions centered around their experience with the course, as a mentee, and using both VR and ZOOM as learning modalities. Mentors were asked to participate in a similar focus group interview (n=12) and were asked similar questions about their experiences as a mentor, with the course, and using both ZOOM and VR as teaching modalities (Appendix F). All interviews were audio recorded and transcripts were generated using otter.ai software (Otter.ai, Mountain View, CA). Transcripts were analyzed for themes and subthemes by two independent research personnel to control for subjective bias, then themes were compared and finalized as a team.

3.2.4.2 Evaluation of Critical Thinking Skills

Critical thinking skills were evaluated for each group at four time points corresponding to oral case presentations at the end of each unit (Figure 3.3). Anatomy faculty at CSU served as judges of each unit's oral presentations, using a modified Critical Thinking VALUE Rubric (originally developed by the Association of American Colleges & Universities (Appendix G)). One rubric was used for each group's oral presentation (32 evaluations total, 4 for each of 8 groups). Due to the COVID-19 pandemic, judges connected remotely via ZOOM to watch the presentations. Judges were renamed to "anonymous" during these sessions, and all students were asked to refrain identifying which modality was used during their unit to prevent bias.

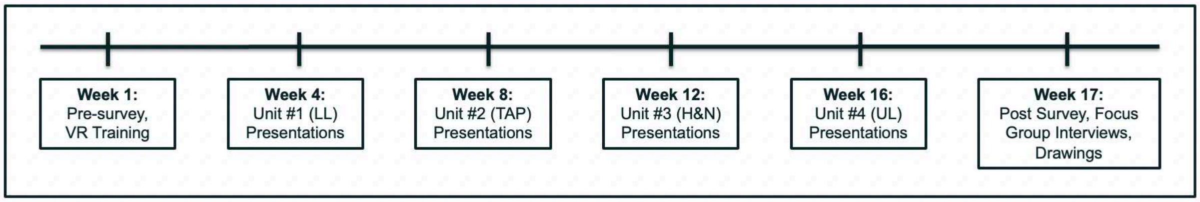

Figure 3.3: Timeline of Research Activities. Students were trained in VR during week 1 and completed a pre-survey. At the end of each unit (weeks 4, 8, 12, and 16), research personnel anonymously evaluated changes in critical thinking skills during each group's oral case presentation. At the conclusion of the semester, students completed a post-survey, focus group interviews, and drawing activities.

Results were analyzed by creating a mixed effects model, establishing "Unit" and "Modality" as fixed effects and "Group" as a random effect. The model was analyzed using a Type III ANOVA analysis with the Kenward-Roger's method to assess the size of each effect and to quantify possible association of effects. Further analysis was conducted using pairwise comparisons, contrasting 1) the two modalities within each unit and 2) each modality longitudinally across all units. Since groups alternated modality each unit to allow for equal access to education resources, establishing group as a random effect controlled for this variability in the chosen model. All statistical analyses were conducted using R Software (The R Foundation for Statistical Computing, Vienna, Austria), and figures were generated using GraphPad Prism 9 version 9.1.1 for Mac (GraphPad Software, La Jolla, CA, USA). Though groups were randomly assigned at the beginning of the semester, group means were still calculated within each unit and longitudinally to ensure that no group outliers were present.

3.3 FINDINGS

3.3.1 Student and Mentor Perceptions

Overall, students reported feeling more motivated, comfortable, and engaged with learning content while using VR compared to online interactions. Students reported significantly higher motivation (4.25 ± 1.00 VR; 3.27 ± 1.27 online, $p = 0.04$) and overall comfort (4.17 ± 0.98 VR;

3.08 ±1.12 online, $p < 0.01$) while using VR, as well as non-significant increases in both satisfaction (4.14 ± 0.64 VR; 3.50 ± 1.04 online, p = 0.06) and overall engagement (4.28 ± 0.75 VR; 3.86 ± 0.76 online, p = 0.11) compared to the online control (Figure 3.4a). When asked specifically about perceived engagement, students reported higher engagement in learning anatomical content (4.28 ± 0.57 VR; 3.52 ± 1.31 online, p = 0.037) while using VR. Students felt equally engaged with their peers (3.36 ± 1.43 VR; 3.00 ± 1.24 online, p = 0.27) and mentors (4.61 ± 0.70 VR; 4.17 ± 0.92 online, p = 0.12) in both modalities (Figure 3.4b). Students reported feeling more comfortable in VR overall, but reported equally high comfort levels in both modalities when interacting with their mentors (4.5 ± 0.79 VR; 4.28 ± 0.83 online, p =0.44), peers (4.06 ± 1.26 VR; 3.77 ± 1.31 online, p = 0.39) and anatomical content (4.36 ± 0.68 VR; 3.69 ± 1.15 online, p = 0.06) (Figure 3.4c).

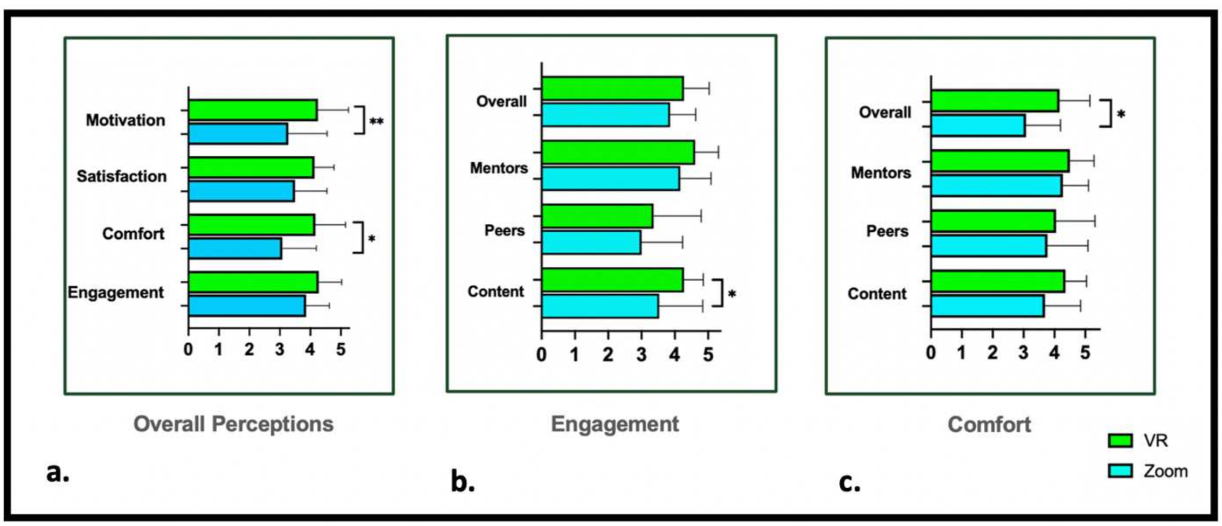

*Figure 3.4: Student Perceptions of VR and Online Interactions. Students were asked to rate their motivation, satisfaction, comfort, and engagement with both modalities using 5pt Likert scale questions (a). Students were further asked to rate their perceived engagement (b) and comfort (c) interacting with mentors, peers (student groups), and anatomical content between the two modalities. Results were analyzed using the nonparametric Wilcoxon Signed Rank (Pairs) test. Significance indicated by * (p<0.05). n = 18*

Similarly, mentors reported higher motivation and engagement with anatomical content in VR, as well as increased satisfaction. Mentors reported higher motivation (4.9 ± 0.32 VR; 3.3 ± 1.49 online, p = 0.023) and higher satisfaction (4.60 ± 0.52 VR; 3.5 ± 1.35 online, p = 0.03) while using VR, as well as a nonsignificant increase in overall engagement while using VR compared to the online control (4.6 ± 0.52 VR; 4.0 ± 1.16 online, p = 0.17) (Figure 3.5a). When asked specifically about perceived engagement, mentors reported a significantly higher engagement with anatomical content (4.9 ± 0.32 VR; 3.7 ± 0.82 online, p = 0.008) in VR. Mentors felt equally engaged in the two modalities when interacting with fellow mentors (4.5 ± 0.71 VR; 4.3 ± 1.0 online, p = 0.81) and student groups (4.3 ± 0.82 VR; 4.0 ± 0.94 online, p = 0.63) (Figure 3.5b). Mentors also reported feeling equally comfortable in both modalities overall (4.60 ± 0.52 VR; 4.60 ± 0.69 online, p > 0.99), with fellow mentors (4.7 ± 0.67 VR; 4.7 ± 0.48 online, p >0.99), student groups (4.8 ± 0.42 VR; 4.4 ± 0.97 online, p = 0.5), and while learning anatomical content (4.8 ± 0.42 VR; 4.6 ± 0.70 online, p = 0.75) (Figure 3.5c).

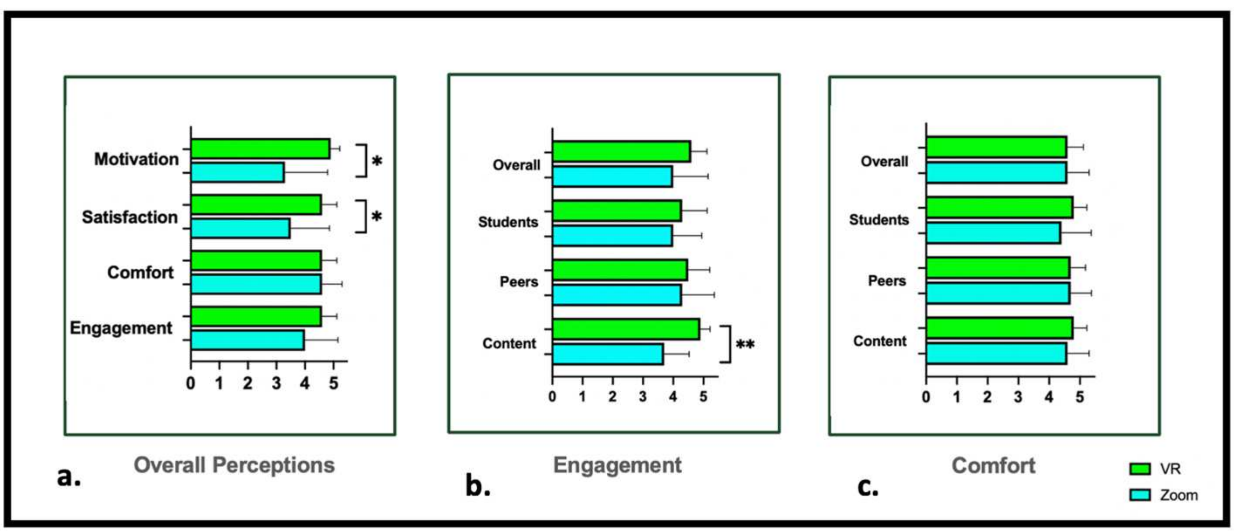

Figure 3.5: Mentor Perceptions of VR and Online Interactions. Mentors were asked to rate their motivation, satisfaction, comfort, and engagement with both modalities using 5pt Likert scale questions (a). Mentors were further asked to rate their perceived engagement (b) and comfort (c) interacting with student groups, peers (fellow mentors),

*and anatomical content between the two modalities. Results were analyzed using the nonparametric Wilcoxon Signed Rank (Pairs) test. Significance indicated by * ($p < 0.05$). n = 10*

3.3.2 Focus Group Interviews

Student and mentor focus group interviews were conducted at the end of the semester. Students were separated into three focus groups of six students to keep groups relatively small and were interviewed in-person. Mentors were interviewed virtually in one group of 12, as mentor schedules only aligned during a previously scheduled monthly meeting. The objective of these focus group interviews was to gain a better understanding of student and mentor's experience with the course, with each other, and with VR. Students and mentors were asked similar questions (Appendix F). Participants were asked to discuss their initial impressions using VR in the classroom, how VR/online learning facilitated connection between mentor and student, positive and negative experiences using VR/online learning, differences in learning/teaching approaches between the two modalities, and how students/mentors grew personally throughout the semester.

In response to the Question #1, "Describe your initial impressions using VR in this course?", primary themes that emerged included VR's user friendly/intuitive nature, the learning curve, initial technical difficulties, the students' love for the interactive/active learning component, and the fact that learning in VR was overwhelmingly fun and engaging (Appendix F).

When asked how online interactions and VR promoted connection to student groups/mentors (Question #2 and #3), both students and mentors reported that VR promoted connection by providing an engaging in-person feel but detracted from connection through its audio-centric interaction. That is, participants disliked that they could not see each other's faces in VR and enjoyed the face-to-face connection of online interactions. Mentors additionally reported that VR was initially more difficult as there is no established "etiquette" for VR interactions. For example, during online interactions participants know to mute when not actively talking, whereas no such implicit rules exist in VR. Lastly, mentors reported that VR facilitated connection more naturally through interactive and experiential learning experiences.

When asked how they approached their case study differently in VR vs online (Question #4), students and mentors reported that online interactions focused on assignment requirements, were solution-oriented, and focused on acquiring baseline knowledge and passive transmission of information. Students and mentors both reported that VR was uniquely beneficial for making connections and using knowledge to solve a problem, while online learning assisted in baseline knowledge acquisition. In VR, students felt that their learning focused more on content/anatomy material and making connections, as well as active/interactive learning and problem solving (Table 3.1). Mentors additionally reported that their students came more prepared to VR sessions, which they believed was because students knew they would not be able to look at notes regularly while in these sessions.

When asked about positive and negative feedback about using VR (Question #5), primary positive themes from all focus groups included that VR was very interactive, made connecting material more intuitive, and served as a unique and intuitive method of visualizing anatomy in 3D. Additional themes that emerged from the focus group interviews included an appreciation of the intuitive nature of spatial relationship in VR, and use of CT/MRI data to enhance learning about their case studies. Overall themes surrounding student/mentor dislikes included the initial technical difficulties, the inconvenience of using VR remotely (from home, due to COVID), no facial cues, and the fact that students could not take notes in VR. One student also discussed feeling motion sick while using VR.

Table 3.1: Learning Online vs Learning in VR: Benefits to Both. Themes generalized from findings of both student and mentor focus group interviews. Themes were found using an open coding scheme on all recorded interview transcripts.

Online Learning	VR
• Focused on assignment requirements • Solution-oriented • Focused on baseline knowledge • Transmission of info-passive learning • Focused on taking notes • Less prepared • Greater diversity of learning materials	• Focused on content/anatomy • Focused on making connections • Using knowledge to solve a problem • Active role in learning/exploratory learning • More prepared and accountable • Retain information better

In response to Question #6, "How do you feel that you/your student groups have grown throughout the semester in this VR, case-based course?" students and mentors each reported extensive growth areas in interpersonal communication, confidence, public speaking skills, and problem-solving skills (Figure 3.6).

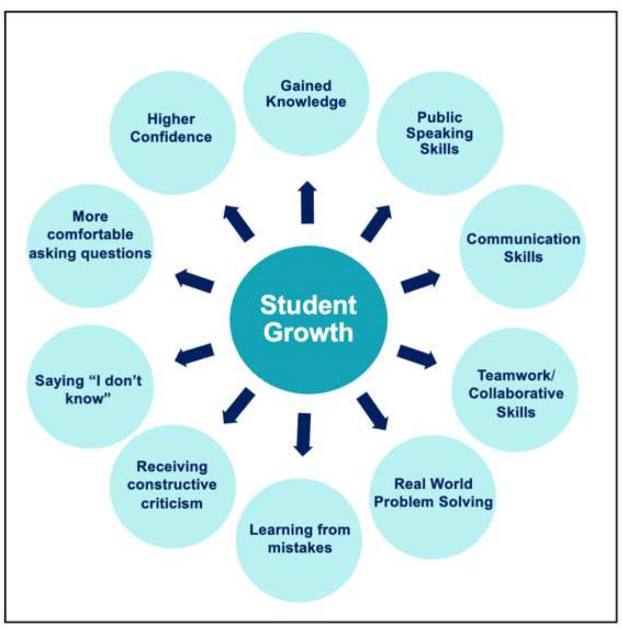

Figure 3.6: Student Perceived Growth During Course. In a focus group interview question, students were asked to answer the following question: "How did you grow throughout the semester in this VR, case-based course?" Mentors were also asked how they perceived their students grew. Responses were audio recorded and later analyzed for themes by two independent graders, who finalized findings as a team. These results represent dominant themes identified from both student and mentor focus groups.

3.3.3 Critical Thinking

As a whole, the high school class improved critical thinking skills steadily throughout the semester. The class mean scores in critical thinking ability improved significantly between the second and third unit (13.73, Unit 2; 15.96, Unit 3, $p = 0.03$) second and fourth unit (13.73, Unit 2; 16.73, Unit 4, $p < 0.01$), and first and last unit (13.04, Unit 1; 16.73 Unit 4, $p < 0.01$) (Figure 3.7a).

Changes in critical thinking ability were not significantly affected by modality used (VR vs. Online), but there was a significant effect size between unit and critical thinking score; however, further analysis suggests that VR may promote critical thinking skills longitudinally compared to the control (Figure 3.7). An ANOVA of the mixed effects model revealed a significant effect of unit on score ($p < 0.01$), and no significant effect of modality on score ($p = 0.95$). Additionally, there was no significant relationship between unit and modality effects ($p = 0.74$). Further, comparison of the differences of means between modalities within each unit corroborate these findings, finding no significant differences. However, when contrasting the means of one mode longitudinally across all units (controlling for group as a random effect), there is a significant increase between the first and last unit in VR, but no corresponding increase in ZOOM (Figure 3.7b).

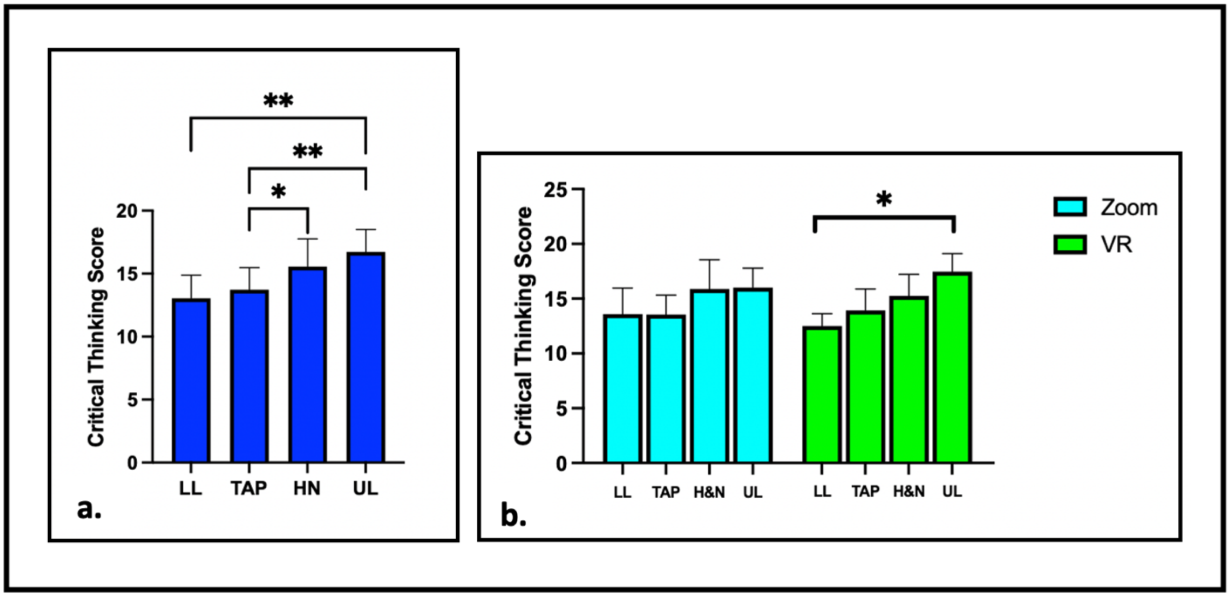

*Figure 3.7: Critical Thinking Scores from Group Case Presentations. Class changes in critical thinking ability (a) and longitudinal changes in critical thinking ability by modality (b). Presentations were graded by anonymously using a modified version of the Critical Thinking VALUE Rubric, originally developed by the Association of American Colleges & Universities. Presentations were orally presented by groups of 4-5 at the end of each unit (LL = Lower Limb; Unit #1, TAP = Thorax, Abdomen, Pelvis; Unit #2, H&N = Head and Neck; Unit #3, UL = Upper Limb; Unit #4). Responses were analyzed using a Linear Mixed Effects Model, ANOVA, and pairwise comparisons. Significance indicated by * ($p<0.05$). n = 8 groups, 35 students.*

3.4 DISCUSSION

3.4.1 VR as a Tool for Distanced Connection and Collaboration

The need for distance education is ever increasing, and it is therefore essential to continue advancing distanced pedagogical techniques to provide exceptional and equitable education to students. The use of VR as a tool in distance education is in its infancy stage but has been successfully documented in several areas of STEM including chemistry, anatomy, neuroanatomy, physical science, and ecology distanced classrooms (Salvadori et al., 2016; Moro et al., 2017; Stepan et al., 2017). These descriptions suggest VR provides unique benefits to the remote learner through several important areas: 1) providing an environment which can be readily manipulated to serve diverse learner needs, 2) promoting a feeling of social presence by connecting students in a common virtual environment, 3) holding learner attention and engagement, and 4) challenging learners to take an active role in their learning and derive their own meaning from content presented. Each of these points address key challenges imposed by traditional distance education methods, so further exploration of VR in distance education is important.

The present study hypothesized that 1) VR is an effective tool to remotely link graduate student mentors with high school students, promoting student engagement and motivation. The results of this study demonstrate VR as a novel tool to promote connection and an in-person feel, virtually. Both students and mentors reported VR affording an "in-person feel" compared to online interactions, noting that "It was like we were in a room together in completely different cities." One of the major challenges of distance education is the prevalence of student-perceived social isolation and feelings of disconnection (Cesari et al., 2021). Through its real-time audio feedback, spatial orientation and interactive ability, VR allows mentors and students to form genuine connections with each other and collaborate around a common virtual cadaver, promoting group cohesion and immersing the users more fully in their learning and teaching endeavors.

3.4.2 VR Promotes User Engagement and Motivation

Though limited, previous literature exploring the role of VR in the classroom has repeatedly shown a high levels of learner engagement, satisfaction, perceived usefulness, and motivation (Altmeyer et al., 2020; Dunnagan et al., 2020; Ekstrand et al., 2018; Moro et al., 2017; Stepan et al., 2017). Though studies have not conclusively reported on VR's benefit in long term knowledge retention, several of the above studies have discussed the intrinsic benefits of VR to the overall learning experience.

The present study adds to existing literature by demonstrating the benefit of VR in improving overall learning experience and provides new evidence of the effectiveness of using VR as a collaborative tool in distance education to promote learner engagement, motivation, and satisfaction. Students in this study reported a significantly better learning experience using VR compared to online methods, indicated by a higher motivation, comfort, and engagement with anatomical content while using VR. Importantly, though participants perceived equally high engagement in online and virtual interactions, both mentors and students reported higher "content engagement" in VR compared with ZOOM. That is, students and mentors were more engaged with the learning and teaching process. VR is a completely immersive experience, allowing the learner to be fully present and to explore content in their own unique way. Students can derive their own meaning of the material through such personalized instruction, and the present study suggests that these highly personalized and unique interactions promote student engagement, satisfaction, and motivation in learning. While students reported a significantly better learning experience in VR, mentors reported a corresponding improved teaching experience while utilizing VR compared to online methods, indicated by higher motivation, satisfaction, and content engagement.

Of note, the study asked students to compare their comfort in VR and online to ensure that students were not uncomfortable using new technology in the classroom. Interestingly, students rated their comfort as substantially higher in VR vs using an online learning platform. Mentors reported equal comfort levels between the two modalities of teaching. Both findings are reassuring that VR did not detract from the overall learning and teaching environment by making students and mentors uncomfortable in their virtual environment.

3.4.3 VR Promotes Knowledge Application and Making Meaningful Connections

Focus group interviews shed further light to the advantages of VR in the classroom. When asked how they approached cases differently in online interactions compared to VR, both students and mentors described online interactions as useful for initial learning, and VR as most helpful in applying knowledge to make connections. Students routinely used language to indicate passive learning while describing online interactions, and active language when referring to time spent in VR (see Appendix F for examples). This suggests that VR naturally promotes an active role in learning, as learners are free to interact with and explore their environment to make meaning of content. Active and experiential learning have been extensively tied to higher retention and higher learning outcomes, but more research is needed here to better quantify the role of VR.

Students reported using online time with mentors primarily for completing assignment requirements, finding answers, and for initial learning of relevant anatomical content. Conversely, students described VR as useful in "making connections," "applying knowledge" and "using knowledge to solve a problem" (Appendix F). Both students and mentors preferred online mediums for baseline learning and transmission of information, and VR for expanding their knowledge base. Both groups reported difficulty when beginning new content in VR, suggesting that users are more likely to have an optimal experience in VR with a solid foundation in content first. Foundational knowledge allows the learner to explore BananaVision to a fuller extent, as they are oriented to the content and can use their baseline knowledge to more fully explore anatomical structures.

Both students and mentors repeatedly discussed VR's limited capability for notetaking; because students are fully immersed in the program when wearing HMD's, it is difficult to take substantial notes without repeatedly removing and replacing their headset. Of note, while students reported this as a negative program feature, mentors felt that this was a positive aspect. Students reported frustration at not being able to reference their notes or write down notes from their mentor meetings. Mentors, however, reported that students in VR came more prepared, which they believed was partially because they knew they wouldn't have access to notes, and therefore were motivated to review relevant material more extensively beforehand. This suggests that VR may add a new level of accountability for learners, encouraging them to prepare beforehand and come ready to expand their existing knowledge and engage in their learning.

3.4.4 Role of VR in Development of Critical Thinking Skills

Critical thinking skills are an important skill for student success. The literature agrees that students who develop robust critical thinking skills are highly prepared for future professional schooling and/or industry (Abrami et al., 2015; Evans, 2020; Facione, 1990). Problem-based learning has emerged as an important component of development of critical thinking skills, and the presented study utilized case studies as a method to engage students in problem-solving. The present study proposed that, through increased immersion, engagement, and motivation, students in VR would develop greater critical thinking ability compared to online controls.

The results of this study suggest that this case-based, VR course longitudinally improved critical thinking skills. That is, students improved critical thinking ability throughout the semester, but this improvement was not dependent on the modality they used within a given unit. However, VR groups improved their critical thinking ability significantly longitudinally, while online groups did not. This suggests that VR may have an additive benefit, increasing critical thinking skills over longer periods of time. This may indicate that VR is most beneficial when used longitudinally, rather than in short increments or stand-alone instances. However, more research is needed here to better quantify the role of VR in development of critical thinking skills.

3.5 LIMITATIONS

This study was conducted during the COVID-19 pandemic, adding complexity to the course itself and study design. An immense amount of coordination and collaboration took place to respect social distancing guidelines and to accommodate learners who needed to quarantine due to infection or exposure to the virus.

During oral presentations, groups variably had 1-2 members present virtually due to viral exposure. For VR groups, this may have adversely impacted the amount of time students were able to spend in VR, as they were required to be present at school to use this technology. Conversely, ZOOM was a more convenient option in these cases, as students could still connect with their mentor from home. This may have positively impacted student perceptions of using ZOOM, and negatively affected perceptions of VR. This may explain student negative feedback comments that VR was inconvenient/inaccessible when not in the classroom.

Student groups and mentor assignment remained constant throughout the semester, but each mentor took a slightly different approach to working with their students. It is possible that group oral presentation scores were skewed by the competence of their assigned mentor – for example, some mentor groups created drawings and quizzes to coach students, while others focused on the assignment requirements. Mentors were given the option of meeting with their student groups for up to one hour outside of class to assist with case study presentations – though most mentors took this opportunity, some did not. This could have skewed some group presentation scores. Additionally, groups themselves functioned differently. Some groups seemed naturally more organized and fluent in anatomy, while others consistently struggled with the content and with finishing presentations. This study evaluated the total mean presentation score of each group to ensure that there were no significant differences between groups – it is reassuring that group means were not significantly different across the semester.

Lastly, this study compared the effectiveness of using VR to using online methods, not to in-person methods. It is possible students preferred VR because of its novelty, especially when all other coursework had an online (computer-based) component due to the nature of the pandemic. Further research is needed to duplicate the presented findings, and to compare VR to in-person learning experiences.

3.6 FUTURE WORK

Future research should compare engagement in VR and in-person learning experiences. Additionally, engagement data should be collected longitudinally to evaluate the effect of novelty, which may wear off after time. Lastly, the role of VR in student spatial ability should be evaluated, as well as its role in assisting in knowledge acquisition and retention.

3.7 CONCLUSION

The present study aimed to explore the role of VR in distance education in a VR, case-based curriculum that connected rural high school students to graduate student mentors. Overall, VR served as a useful tool for creating virtual connection and fostered collaboration, providing an in-person learning feel to students and mentors separated by distance. VR increased both student and mentor motivation and engagement in learning/teaching anatomical content and was uniquely useful for making concept connections and applying existing knowledge to solve a problem. Students reported that they preferred using VR to expand an existing knowledge base, rather than using it as a tool for baseline learning. VR challenged students to take an active role in their learning and promoted learner accountability. Evaluation of critical thinking ability of groups may suggest that VR has an additive, longitudinal benefit to critical thinking ability, but more research is needed here. Virtual Reality is an emerging technology that may transform distance education into a more connective, collaborative, and engaging method of exceptional and equitable virtual learning.

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CHAPTER 4 : SUMMARY AND CONCLUSION

The goal of the studies presented in the preceding chapters was to explore the role of VR in distance education as a novel tool to promote connection and collaboration in a common virtual environment. Both studies utilized a mixed methods approach, including both quantitative and qualitative evaluation metrics to provide a full picture of participant experience using VR.

The study in Chapter 2 aimed to investigate the role of VR in distance education in an undergraduate online human anatomy course. Qualitative data were collected on student engagement, confidence, and reactions to the new technology. Quantitative data assessed student knowledge acquisition and retention of anatomical spatial relationships. Overall, the virtual classroom maintained the rigor of traditional gross anatomy laboratories without negatively impacting student examination scores and provided a high level of accessibility, without compromising learner engagement. Students especially appreciated the unique aspects of the program that were not replicable in an in-person cadaver lab, such as the ability to infinitely scale and isolate anatomical systems on the virtual cadaver. In addition, mixed results showed equivalent retention of anatomical spatial relationships between instruction modalities. This suggests that VR offers unique benefits as a novel instruction tool in human anatomy. This study contributes to the existing literature on how to effectively incorporate VR into an anatomy curriculum, as it addresses a variety of learners and offers a critical lens for restructuring curricula. Furthermore, it provides valuable information that can be applied to other online classrooms that struggle to hold student engagement, particularly those that are facing challenges posed by Covid-19 restrictions.

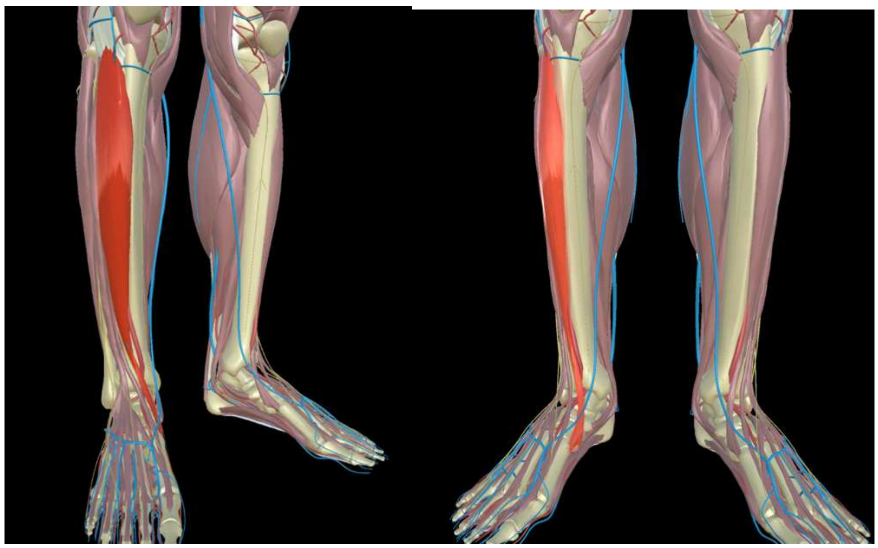
The study presented in Chapter 3 aimed to investigate the role of VR in distance education in a VR, case-based curriculum that connected rural high school students to graduate student mentors. Qualitative data assessed student motivation, mentorship engagement, satisfaction, and overall perceptions while utilizing the VR program compared to traditional online methods. Quantitative data assessed changes in student critical thinking ability throughout the semester. VR increased both student and mentor motivation and engagement in learning/teaching anatomical content and was uniquely useful for making concept connections and applying existing knowledge to solve a problem. Students reported that they preferred using VR to expand an existing knowledge base, rather than using it as a tool for baseline learning. VR challenged students to take an active role in their learning and promoted learner accountability. Evaluation of critical thinking ability of groups may suggest that VR has an additive, longitudinal benefit to critical thinking ability, but more research is needed here. Overall, VR served as a useful tool for creating virtual connection and fostered collaboration, providing an in-person learning feel to students and mentors separated by distance.

Overall, these studies provide a strong argument for the use of this novel VR technology in remote classrooms. Current distance education methods struggle to hold student engagement and attention, so implementation of VR could be a key element to promote student engagement, motivation, and satisfaction with their online learning. Mixed results also indicated that VR may boost spatial ability, critical thinking ability, and course performance, but more quantitative data is needed here. Virtual reality is an emerging, cutting-edge technology that may transform distanced education into a more connective, collaborative, and engaging method of exceptional and equitable virtual learning.

SUPPLEMENTAL MATERIALS

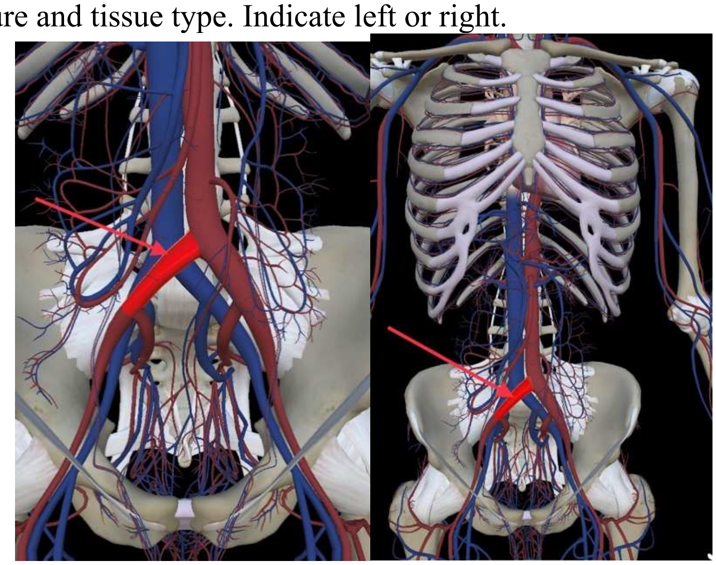
Appendix A: Example Laboratory Examination Questions

Unit 1: Lower Limb
Name the tagged structure and tissue type.



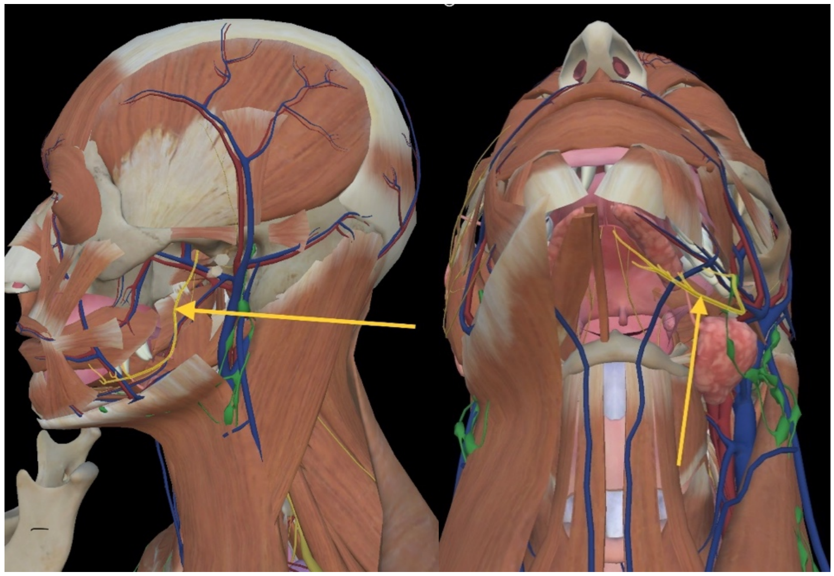
Correct answer: Tibialis anterior muscle

Unit 2: Thorax, Abdomen, and Pelvis
Name the tagged structure and tissue type. Indicate left or right.



Correct answer: Right common iliac artery

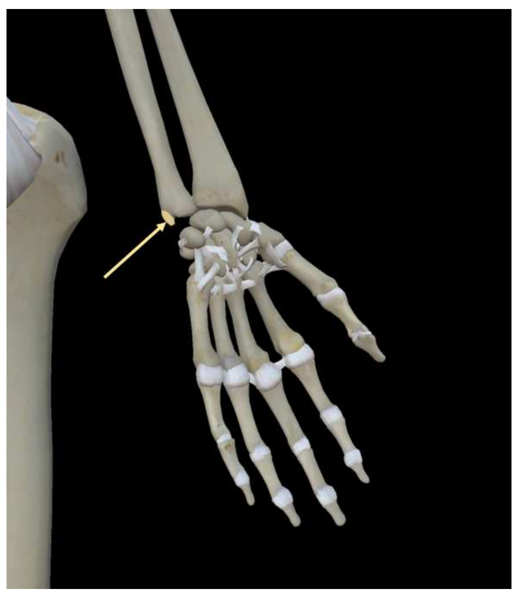
Unit 3: Head and Neck
Name the tagged structure and tissue type.



Correct answer: Inferior alveolar nerve

Unit 4: Upper Limb

Name the bony landmark and bone.



Correct answer: Styloid process of the Ulna

Appendix B: Example Lecture Examination Questions

Unit 1: Lower Limb

The articulation between the femur and patella is described as a:

- Synovial biaxial joint
- Synovial gliding joint
- Synovial multiaxial joint
- Synovial uniaxial joint

  Correct answer: Synovial gliding joint

Unit 2: Thorax, Abdomen, and Pelvis

Which is an adult remnant of a fetal shunt between the pulmonary trunk and aorta that bypassed the lungs in fetal life?

- Ductus arteriosus
- Fossa ovalis
- Foramen ovale
- Ligamentum arteriosum
- Ligamentum venosum

  Correct answer: Ligamentum arteriosum

Unit 3: Head and Neck

The anterior belly of the digastricus muscle is innervated by the Mandibular nerve and the posterior belly of the digastricus muscle is innervated by the _______________ nerve.

- Facial
- Glossopharyngeal
- Mandibular
- Maxillary
- Vagus

  Correct answer: Facial

Unit 4: Upper Limb

A lesion to the radial nerve would present with which movement disability?

- Wrist extension and elbow extension
- Wrist extension and elbow flexion
- Wrist flexion and elbow extension
- Wrist flexion and elbow flexion

  Correct answer: Wrist extension and elbow extension

Appendix C: Student Pre-Survey

What is your major?
- Biomedical Sciences
- Health and Exercise Sciences
- Psychology
- Biology
- Neuroscience
- Other: _____________

What year are you in?
- Sophomore
- Junior
- Senior
- Graduate Student

Have you taken BMS 301 before? If so, when?

____

What are your previous experiences with Virtual Reality (VR)? Select all that apply.
- Entertainment (Gaming, Movies, Amusement parks, etc.)
- Conventions/Events
- Educational
- Fitness
- Therapeutic/Health
- Work
- Other: _________________________

What tools have you used to learn anatomy in the past? Select all that apply.
- Models
- Clay
- Images/Text books
- Small dissections (frog, cat, pig, eye, etc.)
- Visiting schools with cadavers
- System-based approach (Nervous, Muscular...)
- Region-based approach (Lower Limb, Upper Limb...)
- Other:___________________________

What are your hesitations when it comes to using VR in an educational setting?

Appendix D: Student Post-Survey

How would you rate your attendance of the class in total?
- 90-100%
- 75%
- 50%
- < 50%

How many hours per week did you use VR outside of class?
- None
- 1-5 hours
- 5-10 hours
- 10-20 hours
- 20-30 hours

How many hours per week did you use the iPad program outside of class?
- None
- 1-5 hours
- 5-10 hours
- 10-20 hours
- 20-30 hours

What did you like the most about the VR/iPad program?

What did you not like about the VR/iPad program?

How has VR helped you in human anatomy? Select all that apply.
- Anatomical systems (Nervous, Muscular…)
- Recall of anatomical structures
- Functions of anatomical structures (what they do, what they innervate)
- Spatial relationships (Location of structures to one another)
- Using anatomical knowledge to solve a problem
- Understanding anatomical images in a book
- Other: ___________________________

How often were you given interaction opportunities? (1 being rarely and 5 being very often):

Interact with peers	1	2	3	4	5
Interact with instructors/GTA	1	2	3	4	5
Interact with TAs	1	2	3	4	5
Interact with content	1	2	3	4	5
Ask questions	1	2	3	4	5

How comfortable were you during virtual interactions? (1 being the lowest and 5 being highest):

Interact with peers	1	2	3	4	5
Interact with instructors/GTA	1	2	3	4	5

Interact with TAs	1	2	3	4	5
Interact with content	1	2	3	4	5
Ask questions	1	2	3	4	5

In the future, would you enroll in a VR class again?

- Yes
- No
- Maybe

Explain why:

Anything else you would like to share with us?

Appendix E: Post-survey

Rate your satisfaction with using the anatomy VR program (1 being unsatisfied and 5 being very satisfied) 1 2 3 4 5

Rate your satisfaction with using the anatomy iPad program (1 being unsatisfied and 5 being very satisfied) 1 2 3 4 5

How motivated did you feel to use the anatomy VR program? (1 being not motivated, 5 being very motivated) 1 2 3 4 5

How motivated did you feel to use the anatomy iPad program? (1 being not motivated, 5 being very motivated) 1 2 3 4 5

How engaged did you feel while using VR? (1 being not engaged and 5 being very engaged):

Overall Engagement in VR	1	2	3	4	5
Engagement with peers	1	2	3	4	5
Engagement with mentors	1	2	3	4	5
Engagement with anatomical content	1	2	3	4	5

How engaged did you feel while using Zoom? (1 being not engaged and 5 being very engaged):

Overall Engagement with Zoom	1	2	3	4	5
Engagement with peers	1	2	3	4	5
Engagement with mentors	1	2	3	4	5

Engagement with anatomical content	1	2	3	4	5

How comfortable were you during VR interactions? (1 being the lowest and 5 being highest):

Overall comfort with VR	1	2	3	4	5
Comfort with peers	1	2	3	4	5
Comfort with mentors	1	2	3	4	5
Comfort with anatomical content	1	2	3	4	5

How comfortable were you during Zoom interactions? (1 being the lowest and 5 being highest):

Comfort with BanAnatomy program	1	2	3	4	5
Comfort with peers	1	2	3	4	5
Comfort with mentors	1	2	3	4	5
Comfort with anatomical content	1	2	3	4	5

Do you have a preference between meeting with mentors using VR or Zoom?

____ VR _____Zoom/iPad

Explain:

What did you like the most about the VR/iPad program?

What did you not like about the VR/iPad program?

How has VR helped you in human anatomy? Select all that apply.

- ❑ Anatomical systems (Nervous, Muscular…)
- ❑ Recall of anatomical structures
- ❑ Functions of anatomical structures (what they do, what they innervate)
- ❑ Spatial relationships (Location of structures to one another)
- ❑ Using anatomical knowledge to solve a problem
- ❑ Understanding anatomical images in a book
- ❑ Other: _________________________

In the future, would you use VR in a STEM course again?

- ❑ Yes, a fully VR course
- ❑ As a supplemental tool
- ❑ No
- ❑ Maybe

Explain why:

What are your plans after high school (select all that apply)?

- ❏ Attend a community college full time
- ❏ Attend a 4 year university full time
- ❏ Attend a trade school
- ❏ Travel abroad
- ❏ Work part/full time
- ❏ Join the military
- ❏ Other (please specify): _________________
- ❏ None of the above

If you chose to attend a college/university in the future, what major? Otherwise, skip this question.

- ❏ STEM (Science/Technology/Engineering/Math)
- ❏ Business
- ❏ Social Sciences
- ❏ Liberal Arts/Humanities
- ❏ Education
- ❏ Don't know yet!

Appendix F: Focus Group Interview Themes

Tables are organized by question, and include responses from both mentors and students, as themes were mirrored between populations.

Question #1: Describe your first experience using VR. (Students only)

Initial Impressions	**Intuitive/ user friendly**	"Once you learned how to use the controllers and get the headset on, it was pretty simple and easy from there."
		"It was pretty straightforward."
	Learning curve	"In VR, it's a completely different way of [teaching] that I wasn't familiar with myself. And so starting out on VR, I think was just a big learning curve."
		I think [starting in VR] was a really big learning curve, [but] it definitely improved throughout the semester."
	Initial technical difficulties	"I had some technical difficulties, but it's to be expected. VR is new."
		"It was a little dizzy at first, but then once I like got used to it, I thought it was really cool."
	Very fun!	"I think it was pretty fun [and] really nice to visualize things."
		"I thought it was super cool!"

		"I was like super excited to get more involved in it!"
	Loved active/interactive learning	"I thought it was a really, really excellent way to like get to know the structures"
		"It was really cool… being able to see [structures] in front of you and being able to move [structures] and not just looking at something on an iPad or paper."

Question #2: How did VR/online interactions promote connection between student groups and mentors?

Connecting in VR	**In-person feel**	"It was the closest thing that we could get to in-person"
		"It was like we were in a room together in completely different cities."
		"I think VR feels more personable once you get to know each other because it feels like you're standing right next to [your student groups]."
		"I thought that it felt more like you were in the room with your mentor. And then if you asked a question, they could kind of show you on the VR and pointed things and you could move around and it just felt more like you were with them."
	Audio-only interaction	"[In online meetings] we got to see her face and like hear like see her talking and like pointing stuff out when in VR you just see this little like little Lego head."
		"VR was harder because, again, you'll hear [the mentor's] voice but [only see] a little person."
		"It was really interesting being in the headset, just hearing their voice, but not being able to picture their face."

Question #4: How did you/your students approach the case study differently in VR and online?

Approach to Learning	**VR**	**Focused on content/anatomy**	[It was] really helpful to build the foundation of [basic concepts] like muscle actions, and then bring that back into VR to have [students] actually walk through [structures] and get really excited about it.
			"For VR, we were more focused on the actual parts of the body."
			"[VR] was less about the actual questions [and] less about the actual solution. It was [about] having an understanding of the body."
		Focused on making connections	"[We] learned on zoom, and then connected [material] in VR."
			"I liked the VR because I could see [structures] right there, and that helped me like make connections and realize how [structures] were actually working."
			"…VR was much better because you can just sit there and connect things."
			"I felt more confident personally when I was doing VR and not zoom because I could really see what how [structures] correlated with [each other]."
		Using knowledge to solve a problem	"It made me feel good that [my student group] was using their knowledge to answer questions that they didn't know the answer to [in VR].
		Active role in learning	"For me, VR was more hands-on and I was able to understand the content [better]."

			"I feel like VR enables you to learn and experience [the material]. It's like an experiential type of learning where you're in it."
			"VR scratches that kinesthetic part of your brain, and really helps in understanding spatial relationships."
		Higher accountability/more prepared	"Our students never took notes when we were in VR. So I think they knew that we were going to be asking them questions, so they made sure to know their stuff when they came."
			"Our students came more prepared with their case study and anatomy knowledge to VR, because they knew that we were going to be interacting with the body."
		Higher retention	"[During online meetings], [students] just kind of write down notes don't really like think about what they're writing down or what they're learning. But in VR, it's a little more difficult to do that. So they have to listen and kind of process it, learn it more."
			"What I do find when we're in VR is that [our students'] retention of information seems to be much higher."
	Online	**Focused on assignment requirements**	"[Learning online] was a lot more focused on the actual questions we had to answer."
		Solution- oriented	"[Learning online] was focused on the actual solutions we had to find."
		Focused on baseline knowledge	"You learned on zoom, and then connected it in VR."
		Focused on transmission of information	"When we [were online], we could take notes and stuff and learn the structures by themselves."
		Students were less prepared	"Just today, we [met online], and it almost seemed like they had not even read the case. But the last week when we were in VR, [our students] were very prepared.
		Diversity of learning materials	"[During online learning,] our mentors created presentation, and went through to break everything down for us, step by step."
			"[During online learning] our mentor would make drawings for us that were more simplified and were catered to what we were doing."
			"[During online learning] our mentor made mini quizzes for us to make sure that we were actually learning this stuff."

Appendix G: Critical Thinking Rubric

This rubric was used by judges to evaluate group changes in critical thinking skills and is a modified version of the Critical Thinking VALUE Rubric developed by the Association of American Colleges and Universities.

Group # ________________ Case Study Topic:______________________________

	Capstone 4	Milestones 3	 2	Benchmark 1
Explanation of Issues	Issue/problem to be considered critically is stated clearly and described comprehensively, delivering all relevant information necessary for full understanding.	Issue/problem to be considered critically is stated, described, and clarified so that understanding is not seriously impeded by omissions.	Issue/problem to be considered critically is stated but description leaves some terms undefined, ambiguities unexplored, boundaries undetermined, and/or backgrounds unknown.	Issue/problem to be considered critically is stated without clarification or description.
Evidence and Definitions *Selecting and using information to investigate a point of view or conclusion*	Information is taken from source(s) with enough interpretation/evaluation to develop a comprehensive analysis or synthesis. Definitions are correct, and integrated/revisited throughout presentation.	Information is taken from source(s) with enough interpretation/evaluation to develop a coherent analysis or synthesis. Definitions are correct and somewhat integrated/revisited throughout presentation.	Information is taken from source(s) with some interpretation/evaluation, but not enough to develop a coherent analysis or synthesis. Definitions are correct but may be incomplete, and/or are not integrated/revisited.	Information is taken from source(s) without any interpretation/evaluation. Definitions are insufficient and/or incorrect.
Development of a Cohesive Hypothesis	Presentation is cohesive and builds story, takes other viewpoints (other presenters) into account. Specific position (perspective/hypothesis) is clearly thought out, taking into account the complexities of an issue	Presentation follows logical progression, but needs improvement. Builds on *some* other ideas/presenters. Specific position (perspective, thesis/hypothesis) takes into account some complexities of an issue.	Presentation is minimally cohesive, and integrates/incorporates few to no ideas from other viewpoints (other presenters) Specific position (perspective, thesis/hypothesis) is minimally explained, defended or supported	Presentation is fragmented, lacks logical progression, and ideas are not tied together. Specific position (perspective, thesis/hypothesis) is stated, but not well thought out and/or not explained
Conclusions and Related Outcomes (implications and consequences)	Conclusions are logical and reflect student's informed evaluation and ability to place evidence/perspectives in priority order. Conclusion revisits important/critical case information that supports hypothesis with relevant evidence.	Conclusion is logically tied to a range of information. Conclusion revisits some important case information that supports hypothesis with relevant evidence.	Conclusion is logically tied to information (because information is chosen to fit the desired conclusion). Conclusion minimally revisits important case information and lacks supporting/relevant evidence.	Conclusion is inconsistently tied to some information discussed and oversimplified. Conclusion does not revisit important case information. Concluding hypothesis is not well supported.
Student's Position (perspective, thesis, hypothesis) (questions after)	Limits of position are acknowledged; other points of view are synthesized within position. Answers to questions demonstrate thorough ability to apply knowledge to critically evaluate novel information	Limits of position are somewhat acknowledged. Others' point of view is acknowledged within position. Answers to questions demonstrate some ability to apply knowledge to critically evaluate novel information	Limits of position are not acknowledged. Answers to questions demonstrate limited ability to apply knowledge to critically evaluate novel information	Limits of position are not acknowledged. Answers to questions demonstrate little to no ability to apply knowledge to critically evaluate novel information

Notes and Comments: