JSO JOURNAL of STEM OUTREACH

Vol. 6, Issue 1, June 2023

Exploring the Role of Virtual Reality in STEM Distance Education and Remote Outreach Opportunities

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Keywords: Virtual Reality, Distance Education, Human Anatomy, Outreach, STEM Education

Publication Date: June 5, 2023

DOI: https://doi.org/10.15695/jstem/v6i1.11

ABSTRACT: Distance education is essential to modern education; it is therefore crucial to evaluate pedagogical techniques that provide exceptional and equitable education to remote students. Major challenges of online learning include social isolation, feelings of disconnection, and elevated distraction, resulting in lower engagement, motivation, and performance. The present study utilized virtual reality (VR) to remotely connect rural high school students to graduate student mentors to learn human anatomy. Qualitative data assessed student and mentor motivation, engagement, satisfaction, and overall perceptions while utilizing VR compared to traditional online methods. Quantitative data assessed changes in student critical thinking ability throughout the semester. Results indicated increased motivation, engagement, and satisfaction while learning in VR compared to traditional online methods. Focus group interviews further revealed that participants viewed VR as uniquely valuable for applying knowledge and intuitively understanding spatial relationships. Although modality (VR vs online) did not have a significant effect on critical thinking ability between individual units, further analysis suggested that VR may improve student critical thinking skills longitudinally. Research on the implementation of VR in remote 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.

INTRODUCTION

Distance education is essential to the infrastructure of modern education. Once viewed exclusively as an 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).

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). Distance education also enabled remote learning utilized by learners with various disabilities that prevent class attendance and adult learners balancing education with a full-time job and/or family responsibilities (Pregowska et al., 2021). During the COVID-19 pandemic, distance education was the only option available to the majority of students. Post-pandemic, many benefits of online learning such as the broad accessibility, affordability, and flexibility have empowered schools to continue offering online and virtual courses.

Although 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 impact student engagement, attention, and perceived state of flow (Pregowska et al., 2021; Cesari et al., 2021). In physical science, chemistry, and biology, course evaluations of a few carefully designed online laboratories have demonstrated equivalent student outcomes and perceptions when compared to traditional face-to-face laboratories (Brinson, 2015; Dyrberg, 2017; Penn and Ramnarain, 2019). However, the literature agrees that hands-on laboratories can be more difficult to replicate in an online environment as students are limited in their ability to interact with laboratory materials (Moosvi et al., 2019; Sivrikaya, 2019). 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.

Within 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 material. Further, VR enables multiple students to collaborate in a common virtual environment independent of location (Ardiny and 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 (Moro et al., 2017; Stephan et al., 2017; Ekstrand et al., 2018). 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 (Stephan et al., 2012; Moro et al., 2017; Altmeyer et al., 2020; Dunnagan et al., 2020). 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. Specifically, more research is needed to better quantify the role of VR, especially in a fully remote environment.

The present study aims to expand the understanding of 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 such as 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.

METHODS

An 18-week high school anatomy course was designed that incorporated VR into a case-based curriculum and included virtual meetings with graduate student mentors from Colorado State University (CSU). High school students will henceforth be referred to as "students" and CSU graduate student mentors will be referred to as "mentors."

Course Structure and Grading. The 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 assigned to a group of 4-5 peers that remained the same throughout the semester, and a mentor was assigned to each group for the semester. During each unit, each group was assigned an anatomical case study containing relevant anatomy and pathology to the unit. Students worked through 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 and instructors. Each student group solved four clinical case studies over the course of the semester, one case study per region. The unique case studies for each group were designed to be of a similar difficulty by faculty at CSU. Each unit was split into four weeks (Figure 1). Week 1 was used as an introductory week, weeks 2 and 3 were mentor meetup weeks, and week 4 was considered as a 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 study.

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.

BananaVision and BanAnatomy. This course utilized

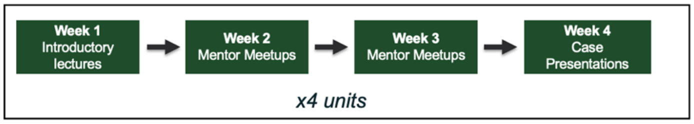

Figure 1. **Unit Outline**. During each unit, students began with an introductory week, followed by two weeks to meet with their mentor and solve their case study. Student groups gave oral case presentations during the last week of each of four units, Lower Limb (LL), Thorax, Abdomen, Pelvis (TAP), Head 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.

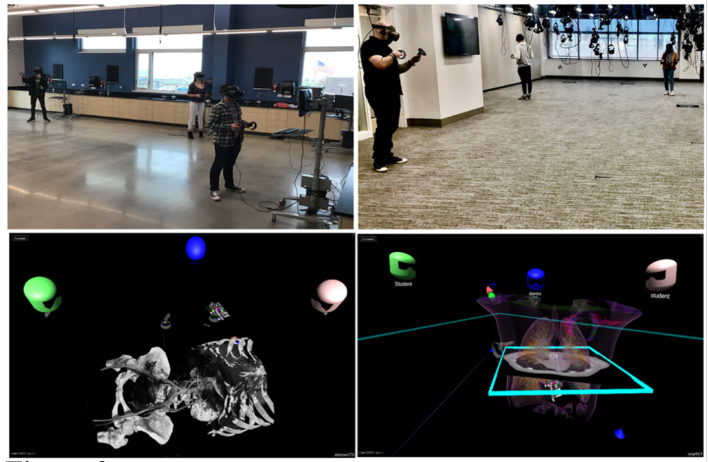

Figure 2. BananaVision. High school students (top left) and graduate mentors (top right) separated by 50 miles remotely connect in common virtual space (bottom) to study human anatomy through case-based learning.

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. BananaVision is a multi-user immersive program that allow users to collaborate, with real-time audio, in a common virtual environment independent of distance (Figure 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.

Participants. Students from a rural high school biomedical science program were recruited for this study. Students were in their third year of high school and had previously taken an introductory anatomy and physiology course as part of their program. All students received written consent from parents or guardians before study participation was granted. All students (n=35) contributed to data collection of the oral presentations and about half (n=18) filled out the pre-survey, post-survey, and participated in the focus group interviews.

Mentors were recruited from a cohort of graduate students in the Department of Biomedical Sciences at Colorado State University. 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. All mentors (n=12) completed the focus group interviews, and the majority (n=10) completed study surveys.

Data Collection and Analysis. Students were asked to complete a printed pre-survey and post-survey at the beginning and end of the semester. Students were assigned a unique identifier to link all surveys. The pre-survey focused on demographic questions as well as previous experience with VR and excitements and hesitations of using VR in the classroom. Participant perceived satisfaction, motivation, comfort, and engagement was compared between ZOOM and VR meetings using a post-survey (Appendix A). These Likert scale questions were treated as continuous data, as there were at least five categories. As the data was not normally distributed, Likert scale data for both students and mentors were analyzed using the Wilcoxon Signed Rank (Paired) 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. Students were split into three focus groups of six (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 experience as a mentor, with the course, and using both ZOOM and VR as teaching modalities. All interviews were audio recorded and transcripts were generated using otter.ai software. Transcripts were analyzed for themes and subthemes using inductive coding, during which two independent graders analyzed the data using an open coding scheme. This was followed by a phase of thematic analysis coding, and finally themes compared between team members to finalize.

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. 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 Amer-

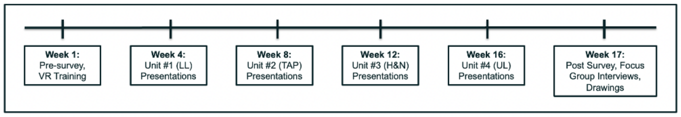

Figure 3. **Timeline of Research Activities**. Students were trained in VR during week 1 and completed a pre-survey. At the end of each unit (weeks 4, 8, 12, and 16), research personnel anonymously evaluated changes in critical thinking skills during each group's oral case presentation. At the conclusion of the semester, students completed a post-survey and focus group interviews.

ican Colleges and Universities [Appendix B]). One rubric was used for each group's oral presentation (32 evaluations total, four for each of eight groups). Judges connected remotely via ZOOM to watch the presentations. All students were asked to refrain identifying which modality was used during their unit to prevent bias.

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 version 1.4.1106 (The R Foundation for Statistical Computing, Vienna, Austria) and figures were generated using GraphPad Prism 9 version 8.4.3 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.

RESULTS

Student and Mentor Perceptions. Overall, students reported feeling more motivated, comfortable, and engaged with learning content while using VR compared to online (ZOOM) 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 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 4b). Though overall students reported feeling more comfortable in VR, they 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 4c).

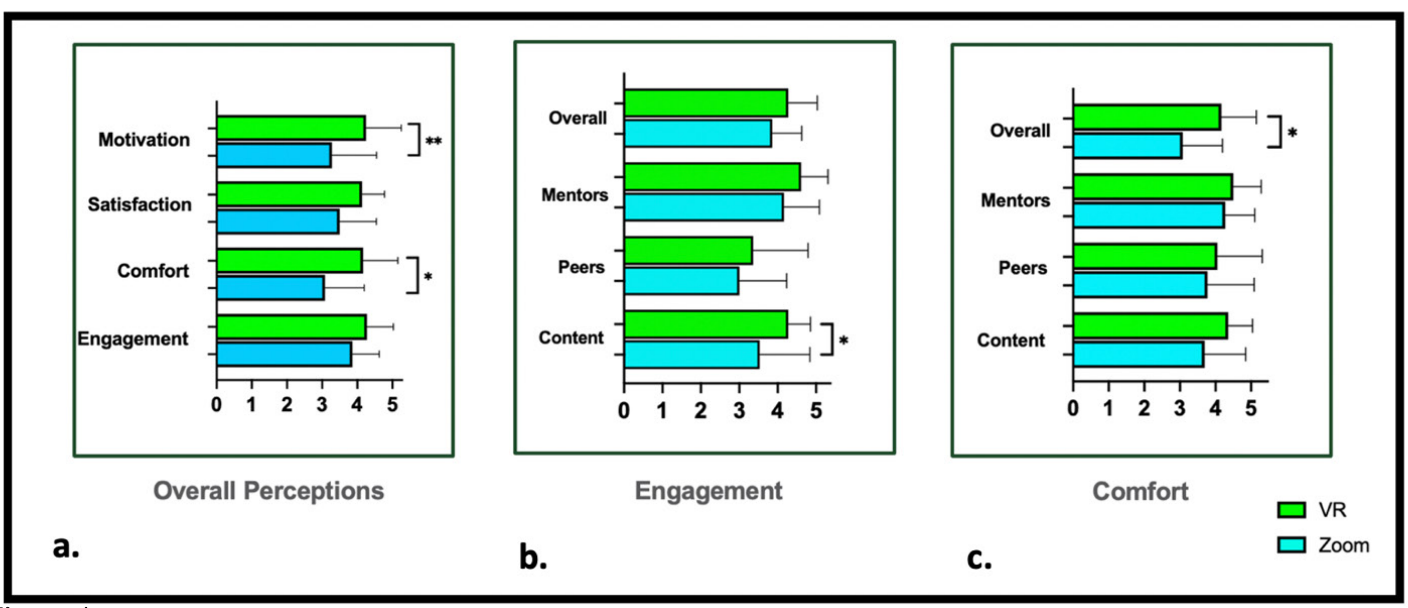

Figure 4. **Student Perceptions of VR and Online Interactions**. Students were asked to rate their motivation, satisfaction, comfort, and engagement with both modalities using 5pt Likert scale questions (a). Students were further asked to rate their perceived engagement (b) and comfort (c) interacting 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

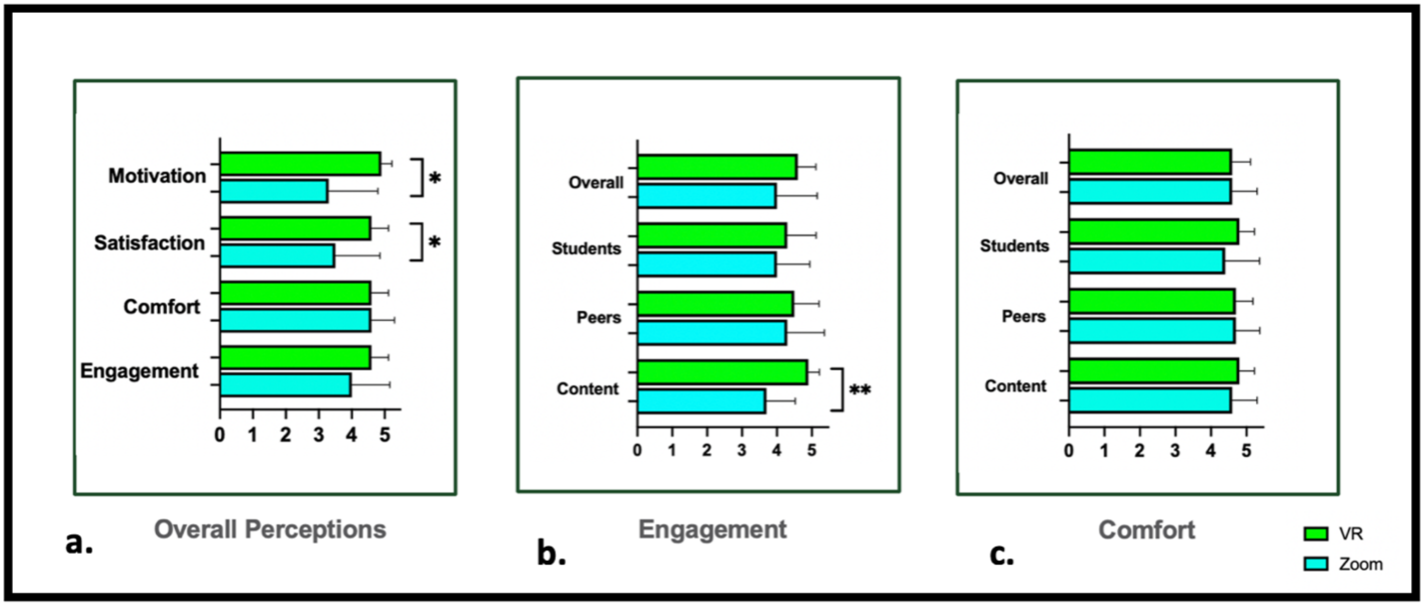

Figure 5. **Mentor Perceptions of VR and Online Interactions**. Mentors were asked to rate their motivation, satisfaction, comfort, and engagement with both modalities using 5pt Likert scale questions. Mentors were further asked to rate their perceived engagement (b) and comfort (c) interacting with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

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 5a). When asked specifically about their 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 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 5c).

Focus Group Interviews. 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 C). In response to the Question #1, "Describe your initial impressions using VR in this course?", primary themes that emerged included VR's user-friendly 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 C).

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 such implicit rules do not yet 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 and making connections, as well as interactive learning and problem solving (Table 1). Mentors additionally reported that their students came more prepared for VR sessions, which they believed was because students knew they would not be able to look at notes regularly while in these sessions.

Table 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

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 cannot take notes in VR. One student also discussed feeling motion sick while using VR.

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 6).

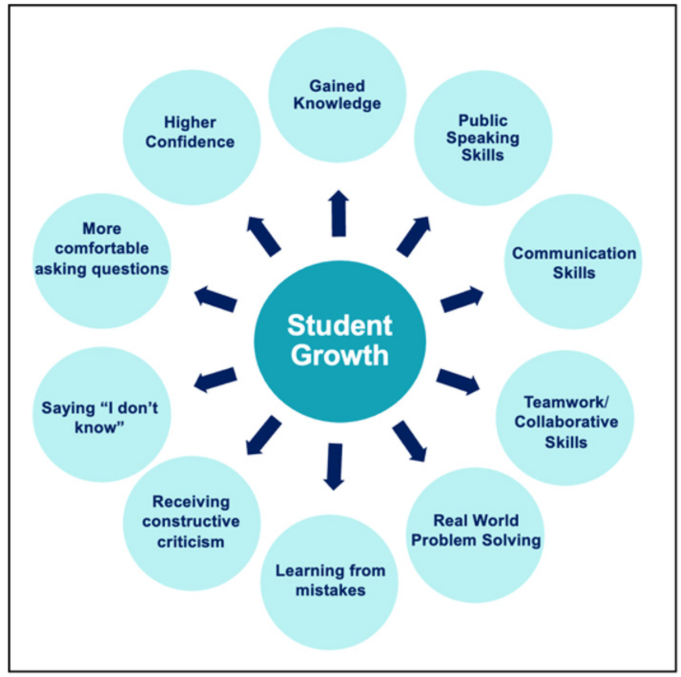

Figure 6. **Student Perceived Growth During Course**. In a focus group interview question, students were asked to answer the following question: "How did you grow throughout the semester in this VR, case-based course?" Mentors were also asked how they perceived their students grew. Responses were audio 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.

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 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 Zoom control. An ANOVA of the mixed effects model revealed a significant effect of unit on score ($p < 0.01$), and no significant effect of mode 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 (Figure 7a). 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 7b).

DISCUSSION

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. Although online learning provides a high level of accessibility and flexibility (Pregowska et al., 2021), current methods promote student-perceived social isolation and feelings of disconnection from peers and content (Cesari et al., 2021). Previous literature suggests that VR may provide 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 (Salvadori et al., 2016; Moro et al., 2017; Stepan et al., 2017).

The present study demonstrates VR as a novel tool to pro-

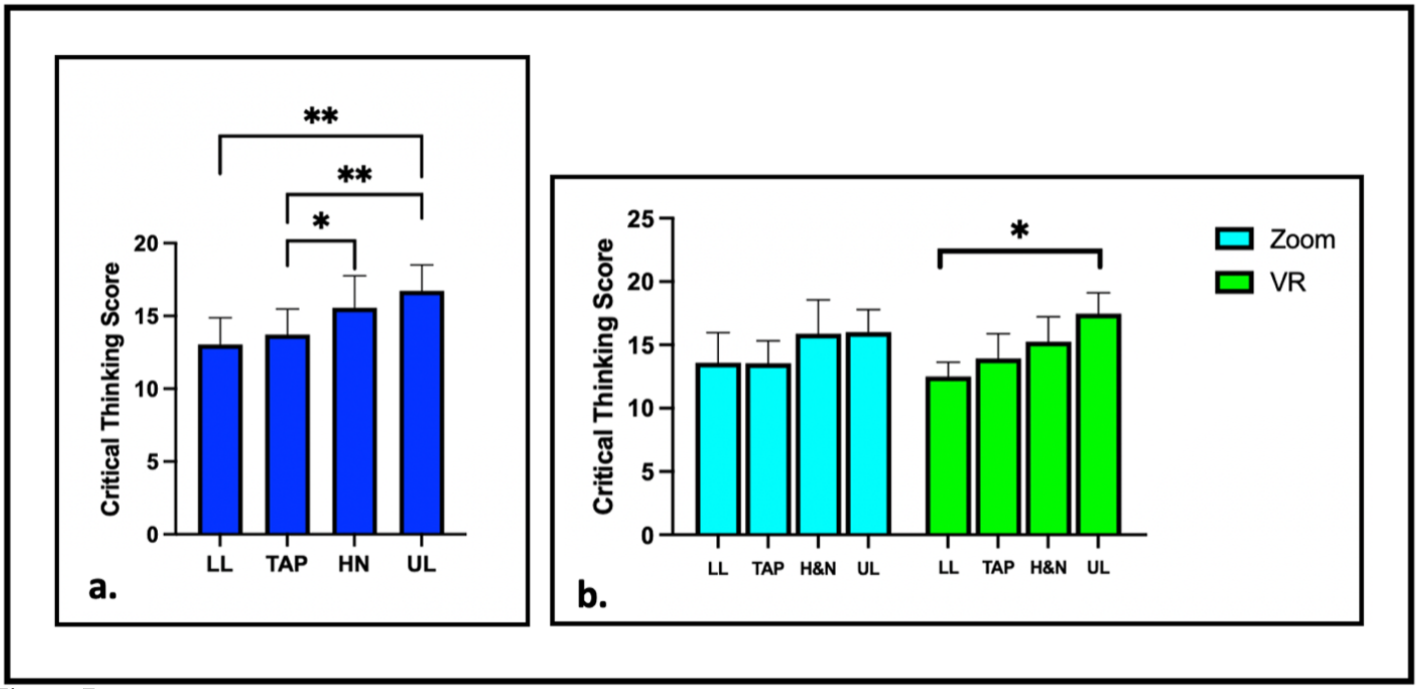

Figure 7. **Critical Thinking Scores from Group Case Presentations**. Class changes in critical thinking ability (a) and longitudinal changes in critical thinking ability by modality (b). Presentations were graded by anonymously using a modified version of the Critical Thinking VALUE Rubric, originally developed by the Association of American Colleges and 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.

mote connection and collaboration in a common virtual environment. 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." Reported challenges of distance education include student-perceived social isolation and feelings of disconnection (Cesari et al., 2021). Through its real-time audio feedback, spatial orientation and interactive ability, VR allowed mentors and students to form authentic 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. The case-based nature of this course further enhanced group work allowing students and mentors to problem solve together as they explore anatomical datasets. It is essential to continue advancing distanced pedagogical techniques to provide exceptional and equitable education to students and allow them to make meaningful connections with their peers.

VR Promotes User Engagement and Motivation. Though limited, previous literature exploring the role of VR in the classroom has repeatedly shown high levels of learner engagement, satisfaction, perceived usefulness, and motivation (Stepan et al., 2017; Moro et al., 2017; Ekstrand et al., 2018; Altmeyer et al., 2020; Dunnagan et al., 2020). Though studies have not conclusively reported on the benefit of VR 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 providing new evidence of the effectiveness of using VR as a collaborative tool in distance education. 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. Both mentors and students reported higher "content engagement" in VR compared with ZOOM. VR is a completely immersive experience, allowing the learner to be fully present and to explore content in their own unique way. The present study suggests that these highly personalized and unique interactions promote student engagement, satisfaction, and motivation in learning. Students reported a significantly better learning experience in VR and mentors reported a corresponding improved teaching experience while utilizing VR.

Additionally, the study asked students to compare their comfort in VR and online to ensure that students were not adversely uncomfortable using new technology in the classroom. Interestingly, students rated their comfort as substantially higher in VR compared to using an online learning platform. Mentors reported equal comfort levels between the two modalities of teaching. These data show that VR did not detract from the overall learning and teaching environment. Further, it is possible the students felt a high level of comfort due to all participants appearing as avatars and working with near-peer mentors; it is feasible that students experienced fewer microaggressions and implicit biases based on social class, gender, ethnicity, and race. However, future research is needed to better quantify this relationship.

It is possible the conditions of the pandemic and the novel offering of VR may have positively affected student engagement. However, the large variety and consistency of positive feedback suggests that students would have enjoyed a high level of engagement using VR and ZOOM regardless of the pandemic, demonstrating that this course offering is suitable for many environments. Students were additionally excited about the opportunity to interact with college students forming near-peer mentor relationships, which likely provided an additional boost to overall engagement.

VR Promotes Application of Existing Knowledge. Active and experiential learning have been extensively tied to higher retention and higher learning outcomes; it is therefore crucial to investigate how to implement these strategies into a virtual environment and to quantify the role of VR. In this study, focus group interviews shed further light to the unique capacities 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 C for examples). This suggests that VR may naturally promote an active role in learning, as learners are free to interact with and explore their environment to make meaning of content.

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 C). 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.

Although both students and mentors discussed VR's limited capability for notetaking while wearing a headset, mentors felt this was a positive aspect as students came more prepared. Mentors believed this was partially because the students knew they would not have access to notes, and were therefore more motivated to prepare more 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.

Role of VR in Development of Critical Thinking Skills. Critical thinking skills are an important skill for student success. This course utilized case-based learning, and 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. However, more research is needed here to better quantify the role of VR in development of critical thinking skills.

LIMITATIONS

This study was conducted during the COVID-19 pandemic, adding several complexities 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. The sample size of this study was rather limited, potentially leading to a lower statistical power of the study findings.

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 in-person 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 impacted 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.

FUTURE WORK

Future research should compare engagement in VR and in-person learning experiences with a full cohort using solely VR and a second cohort using exclusively human cadavers to provide more robust controls. Additionally, engagement data should be collected over multiple semesters to evaluate the effect of novelty, which may wear off after time. The role of VR in student spatial ability should be evaluated, as well as its role in assisting in knowledge acquisition and retention. Lastly, further qualitative research could be collected on the effect of uniform appearance (avatars) on student perceived comfort in relation to diverse race, ethnicity, and social backgrounds.

CONCLUSION

The present study aimed to explore the role of VR in distance education in an immersive, 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 with anatomical content. It was also uniquely useful for 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 a longitudinal benefit to critical thinking ability. These findings address the growing need to investigate the effectiveness of immersive technologies in overcoming barriers to distance learning. This study demonstrates an early exploration of how VR can transform distance education into a more connective, collaborative, and engaging method of virtual learning.

ASSOCIATED CONTENT

Supplemental material mentioned in this manuscript can be found uploaded to the same webpage as this the manuscript.

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ACKNOWLEDGMENTS

We acknowledge the St. Vrain Valley School district leadership their foresight and willingness to support this project. We thank Principal Dr. Brian Young and BMS Instructor Mark Allen for their enormous efforts to make this a meaningful experience for students at Frederick HS and Colorado State University.

ABBREVIATIONS

2D: Two-Dimensional; CSU: Colorado State University;H&N: Head and Neck; LL: Lower Limb; TAP: Thorax, Abdomen, Pelvis; UL: Upper Limb; VR: Virtual Reality

REFERENCES

Allen, I.E., and Seaman, J. (2011). Going the distance: Online education in the United States, 2011. Babson Survey Research Group. Retrieved from: https://files.eric.ed.gov/fulltext/ED529948.pdf

Altmeyer, K., Kapp, S., Thees, M., Malone, S., Kuhn, J., and Brünken, R. (2020). The use of augmented reality to foster conceptual knowledge acquisition in STEM laboratory courses—Theoretical background and empirical results. British Journal of Educational Technology, 51, 611–628.

Anderson, T., and Rivera-Vargas, P. (2020). A critical look at educational technology from a distance education perspective. Digital Education Review, 37, 208-229.

Ardiny, H., and Khanmirza, E. (2018). The role of AR and VR technologies in education developments: Opportunities and challenges. International Conference on Robotics and Mechatronics, 482-487.

Brinson, J.R. (2015). Learning outcome achievement in non-traditional (virtual and remote) versus traditional (hands-on) laboratories: A review of the empirical research. Computers and Education, 87, 218–237.

Cesari, V., Galgani, B., Gemignani, A., and Menicucci, D. (2021). Enhancing qualities of consciousness during online learning via multisensory interactions. Behavioral Sciences, 11(5), 57. doi: 10.3390/bs11050057

Dunnagan, C.L., Dannenberg, D.A., Cuales, M.P., Earnest, A.D., Gurnsey, R.M., and Gallardo-Williams, M.T. (2020). Production and evaluation of a realistic immersive virtual reality organic chemistry laboratory experience: Infrared spectroscopy. Journal of Chemical Education, 97, 258–262.

Dyrberg, N.R., Treusch, A.H., and Wiegand, C. (2017). Virtual laboratories in science education: Students' motivation and experiences in two tertiary biology courses. Journal of Biological Education, 51, 358–374.

Ekstrand, C., Jamal, A., Nguyen, R., Kudryk, A., Mann, J., and Mendez, I. (2018). Immersive and interactive virtual reality to improve learning and retention of neuroanatomy in medical students: A randomized controlled study. CMAJ Open, 6, E103–E109.

Ginder, S.A., Kelly-Reid, J.E., and Mann, F.B. (2018). Enrollment and employees in postsecondary institutions, fall 2017; and financial statistics and academic Libraries, fiscal year 2017: first look (provisional data). National Center for Education Statistics.

Johnson, J.P. (2020). Creating better definitions of distance education. Online Journal of Distance Learning Administration. 23(2).

Khan, B.H. (2006). Flexible Learning in an Information Society. Hershey, PA, USA. Information Science Publishing, (August 7, 2006).

Lederman, D. (2018). Who is studying online (and where)? Inside Higher Ed Online. Retrieved from: https://www.insidehighered.com/digital-learning/article/2018/01/05/new-us-data-show-continued-growth-college-students-studying

Moosvi, F., Reinsberg, S.A., and Rieger, G.W. (2019). Can a hands-on physics project lab be delivered effectively as a distance lab? International Review of Research in Open and Distributed Learning, 20(1). DOI: 10.19173/irrodl.v20i1.3782

Moro, C., Štromberga, Z., Raikos, A., and Stirling, A. (2017). The effectiveness of virtual and augmented reality in health sciences and medical anatomy. Anatomical Sciences Education, 10, 549–559.

National Center for Education Statistics. (2019). Chapter 3: Postsecondary education. Digest of Educational Statistics. Retrieved from https://nces.ed.gov/programs/digest/d18/ch_3.asp

Penn, M., and Ramnarain, U. (2019). A comparative analysis of virtual and traditional laboratory chemistry learning. Educational Perspectives, 37, 80–97.

Pregowska, A., Masztalerz, K., Garlinska, M., and Osial, M. (2021). A worldwide journey through distance education—From the post office to virtual, augmented and mixed realities, and education during the COVID-19 pandemic. Education Sciences, 11(3), 118. https://doi.org/10.3390/educsci11030118

Shahabadi, M.M., and Uplane, M. (2015). Synchronous and asynchronous learning e-learning styles and academic performance of e-learner. Procedia Social and Behavioral Sciences, 176, 125–138. https://doi.org/10.1016/j.sbspro.2015.01.453

Stepan, K., Zeiger, J., Hanchuk, S., Del Signore, A., Shrivastava, R., Govindaraj, S., and Iloreta, A. (2017). Immersive virtual reality as a teaching tool for neuroanatomy. International Forum of Allergy and Rhinology, 7, 1006–1013.