ARTICLE
Feasibility and Utility of a Virtual Reality Laboratory Exercise in an Undergraduate Neuroscience Course

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To improve undergraduate students' understanding of neuroanatomy and structure, we leveraged existing virtual reality infrastructure to create a novel dissection assignment in an undergraduate neuroscience course. Students completed a virtual reality dissection of the central nervous system that augmented status quo instruction in lecture and textbook format. We found that such an assignment is feasible at a regional comprehensive university with intrauniversity partnerships that are mutually beneficial. Results showed positive engagement from students and feasibility of incorporating virtual reality in undergraduate neuroscience courses.

Key words: Virtual reality (VR); dissection; anatomy

Virtual reality (VR) is a promising tool to allow laboratory experiences that would be difficult to provide otherwise in a psychology department without access to wet lab space. We completed the current study to investigate the outcomes of using virtual brain dissection labs in an undergraduate neuropsychology course at a comprehensive regional institution.

In the experience of the first author, psychology students in the required biological basis of behavior course often struggle with understanding neuroanatomy, including the function and structure of the central nervous system. They have difficulty imagining the brain as a three-dimensional organ with interconnecting parts that work together to create cognition. The use of two-dimensional images included in the textbook is insufficient to help them understand the central nervous system's complexity and some students complete an entire semester of neuropsychology without understanding that there are two hemispheres of the brain and that most structures discussed are bilateral. If this crucial piece of information is missed in the fundamentals of the neuroanatomy module, then they struggle to understand lateralized cognition such as speech and facial recognition.

The use of hands-on models to improve student engagement and understanding of medical physiology is supported (Mathew, Chandrasekaran, & Oommen, 2018). However, comprehensive models of the human brain cost upwards of $100 each and still cannot completely differentiate between structures to the level required in a comprehensive neuropsychology course. Sheep brain dissections are similarly cost-prohibitive, and many students are unable or willing to participate in dissections of live tissue (De Villiers & Sommerville, 2005; Lord & Moses, 1994). Another method for teaching neuroanatomy is cauliflower dissections to teach neuroanatomical directions and approximate structures (Masters & Christensen, 2000). This methodology is cheap and uncontroversial but does not allow identifying structures or differentiation of types of tissue.

Providing VR equipment and software to users is a new service that libraries are exploring and evaluating over the past few years. The overall administration needed to create VR services in a library can range from budgetary justifications, software evaluations, and collection development considerations to basic training lesson plans. (Ellern, 2022). Creating a VR Room can be seen as a “skunkworks project”; a laboratory where novel focused projects can be road tested to see if they work in an environment. Libraries have a history of these kinds of endeavors using innovative information technologies (Greenstein & Thorin, 2002). Libraries often see VR and other makerspace initiatives as an extension of their role in the teaching process and can contribute to interdisciplinary learning that bridges departmental silos (Ellern & Cruz, 2021).

VR hardware, such as the Oculus Rift system and the HTC VIVE, combined with 3D Organon software, allows for full immersion into a virtual anatomy laboratory. This human anatomy software allows the user to explore all the body’s subsystems. This software can be used by students at all levels, even as young as those in K-12 science classes (Young, 2020). VR technology is currently used in many medical schools and other health sciences training programs to give students hands-on training in virtual dissections and anatomy and physiology practice (Alfalah et al., 2019; Duarte et al., 2020; McLachlan et al., 2004). The use of VR dissections has also been successful in undergraduate courses, particularly in cardiovascular anatomy (Maresky et al., 2019; McMenamin et al., 2018). The University of Wisconsin Virtual Brain Project has shown success with guided tours of a 3D brain in undergraduate courses, but these were not interactive dissections (Schloss et al., 2021). Students respond well to the novelty of VR, and there is some evidence that they retain and apply the information beyond the VR environment (Jang et al., 2017). It is unknown how undergraduate psychology students respond to this type of intervention and how feasible it is to implement a psychology course at a regional comprehensive university.

Aim 1: Apply a VR dissection experience to an undergraduate neuropsychology course to assess such a lab's feasibility in a psychology course.

Aim 2: Explore the consequences of completing the VR neuroanatomy lab related to the learning outcomes of upper-level neuropsychology courses.

Aim 3: Investigate student experiences and perceptions of VR dissection labs in upper-level neuropsychology courses.

We hypothesized that we would successfully implement a novel VR dissection assignment in an upper-level neuropsychology course. Furthermore, we hypothesized that undergraduate students enrolled in a 400-level neuropsychology course would report positive experiences with the VR dissection lab and meet learning outcomes in neuroanatomy for an introductory neuropsychology course.

Learning Outcomes.

1. Utilize anatomical directions (anterior, posterior, dorsal, ventral, lateral, medial) and show understanding of anatomical planes (saggital, coronal, horizontal).

2. Explore neural structures and begin to associate neuroanatomy with functions.

3. Identify the amygalda and hippocampus and specific location of the limbic system.

MATERIALS AND METHODS

Virtual Reality Equipment

Oculus Rift/HTC VIVE

The virtual reality room at Western Carolina University Hunter Library has been in place and open to all students and faculty for several years. It is equipped with 5 VR stations (2 Oculus Rifts, 2 HTC VIVEs, and 1 PlayStation VR). Each VR gaming-level computer station or gaming console is reservable using the library's scheduling software (SpringShare's *LibCal* system) for the authorized campus community. COVID restrictions (March 2020) closed this room down to everyone until Fall 2021. Before this time, controllers were checked out at the circulation desk once the reservation was confirmed by the library staff. A variety of free software could be downloaded and used on these stations.

For this study (August 29 - October 1, 2021), the VR room was opened to just these undergraduate neuropsychology courses provided COVID-19 precautions were met and the activities in the room were monitored by the teaching assistant (TA) assigned to this study. The TA was trained in the use of the room, the VR equipment, and software, as well as the library and cleaning procedures by the systems librarian who monitored its use over this study period. The TA was debriefed after the study period and this experience will be used to form policies for opening up the area in the coming semester. The students and TA were required to wear masks covering noses and mouth at all times while in the VR room. This is a requirement in all instructional spaces on campus but especially important in this area given that the equipment was directly in contact with faces and hands. Silicone covers were purchased for the headsets and controllers to make them easier to clean. Alcohol wipes were available to the TA and students in the room and used on the keyboards, mice, chair arms, and headsets after each session.

A special calendar was set up in *LibCal* for the times that the TA was scheduled to be in the room. This calendar was set so each request for a session by students defaulted at 1 hour and 15 minutes long. This allowed one hour for the session and 15 minutes for cleaning between sessions. To help minimize the time needed between student sessions, at the beginning of their scheduled time, the TA checked out the controllers and turned on the VR stations making sure they were ready for students' reservations. Most of the students used the LibCal software to schedule their session so after the assignment period, statistics were collected from the software.

3D Organon

The prior year, the library had purchased two copies of 3D Organon software. The library went through a lengthy evaluation and purchasing process for the software. After the return to on-campus teaching, the software was renewed and loaded onto two stations (one of each major VR system – Oculus and HTC) which were separated by 25 feet and cattycorner across the room to allow for physical distancing.

Using the headset and controllers, the 3D Organon software allows users to move each of many body models around. The controllers allow for the selection of various models, changing a model's size, orientation, or height in the center of the room. The user can take each of these models apart by pointing and holding down the selection button on the controllers. Each part within the selected model is labeled, color-coded, and allows the user to move the item around the room. By selecting each piece, the user can look at it from all angles, leave them scattered around the room as they look at other pieces, or put the item back into the model. A bulletin board in the "room" describes in detail each item selected including the functions, connected systems, functions, and even the pronunciation of its scientific name.

Most VR software allows the user to capture the current screen image as a picture file using a combination of controller buttons. This file is usually created from the image projected into one eye of the headset or projected onto any monitor attached to the system. It can be saved onto a folder on the main drive of the computer in a standard picture format (usually jpeg). Students were instructed to save images and email them to themselves.

Participants.

The intervention was implemented at a medium-sized regional comprehensive university in the southeastern United States. Thirty-nine students were enrolled in a neuropsychology course with general psychology as a prerequisite, but no other biology or anatomy. This course fulfilled the "biological basis of behavior" requirement for the psychology major. On average, students had completed 5.63 semesters of post-secondary education. When asked about their gender, 31 students reported that they identified as women, four identified as men, two as agender/gender fluid and two did not report any gender identity. The students were predominantly white and ages ranged from 19 to 24.

Twenty-six students reported never using a VR headset prior to this assignment. Twelve students responded “Yes, but not much” and one student reported, “Yes, several times.” Students were required to complete the VR lab within the first six weeks of the course, after a lecture on neuroanatomy and introduction to the central nervous system.

Procedure.
Within the first six weeks of the course, students in the 3 credit hour Human Neuropsychology course were instructed to sign up for a session with the TA in VR room for this assignment using a link to LibCal posted on the LMS. They were instructed to use LibCal because the library required general user descriptive questions for VR users and has its own vendor safety and health acknowledgments, liability waivers, and safety rules for the VR room that needed to be agreed upon by the student. In addition, before the appointment, consent forms and a copy of the written assignment was distributed via the Learning Management Software (LMS; appendix A). Students were given multiple reminders to sign up for a time slot and all students were compliant in making appointments before the deadline.

The written assignment was due at the end of the six-week period for all students and consisted of instructions on how to navigate the software, specific instructions on capturing a sagittal view of the cerebrum, required three screen shots and descriptions of any three neural structures the student wished, and three questions about the structure of the limbic system.

A total of 193 hours were made available in the 6 weeks the assignment was open and appointments had to be made 24 hours in advance, thus the TA did not have to come to the VR room for hours that were not booked. Because of COVID restrictions, students were only allowed to make one appointment, but in the future students will be able to book additional times to study outside of the TA appointment. Students did not report significant difficulties making appointments and all students completed the assignment before the due date.

The TA worked with each student during their session. They ensured that the headset was worn correctly and comfortably. Once the headset was on, the TA would place the controllers in the student’s handset and demonstrate basic use of the buttons. One of the main objectives of this assignment was to create a screenshot of the dissection of the brain model and email these images to themselves after the session, so special attention was given to the complex button combination to take a screen shot. The TA also gave a brief orientation selecting the correct model, selecting brain structures, and moving the model around in the 3D Organon software VR space. Each student was then encouraged to take about 10 minutes to orient themselves to the device and become comfortable with it before starting the assignment. There was variability in if and how long students took this time; many began the assignment immediately without spending time orienting themselves.

Immediately after the session, students were emailed a Qualtrics survey asking their perceptions of the assignment based on the User Satisfaction Evaluation Questionnaire (Gil-Gomez et al., 2017) and demographic information. Feedback was matched with learning outcomes with student feedback at the end of the semester.

Two students did not complete the VR lab assignment. One student reported vertigo and claustrophobia when they wore the VR headset. The other student was sick during their scheduled appointment and elected to complete the alternate assignment instead.

Alternate assignment
Students who were unable to complete the VR assignment completed the assignment using a three-dimensional brain atlas that was freely available online (Wingate, 2017).

Assessment of learning outcomes.
One week after the VR assignment was turned in, students were given their first exam. Exam was in-class and consisted of 44 multiple choice and short answer questions on topics related to neuroanatomy, action potential, psychopharmacology, and neuroimaging methodology. Seven multiple choice questions and one short answer question related to neuroanatomy covered in the VR lab. Students were given five short answer questions and asked to pick four to answer.

RESULTS

Aim 1: Feasibility.
All students were able to complete the VR session and all but one student turned in the written assignment by the due date. The mean score was 137 out of 150 total points. If students had points taken off it was due to not answering part of the questions or failing to attach the required screenshots. All 39 students provided demographic information, but three did not respond to the user satisfaction survey.

Aim 2: Learning outcomes.
On the seven multiple choice questions related to neuroanatomy, the mean percentage correct was 85.34. The mean percentage correct on the multiple choice questions not related to neuroanatomy or VR was 77.39. The short answer question asked students to identify seven structures outlined on a sagittal view of the brain (occipital cortex, cerebellum, pons, medulla (accepted brainstem as answer), parietal cortex, corpus callosum, and frontal cortex. Students were given up to five points for correct identification of structures and two bonus points for giving the function of the brain area. Label was counted correct if it was approximately in a similar area (ex. basal ganglia instead of corpus callosum). Mean score on this question was 5.19 and all but two students chose to answer this question.

What was difficult about the VR assignment?	Would you recommend the VR assignment be used in future classes?
I wear glasses and it was a lot to have on my face at one time. I also couldn't really see because one of the lenses in the VR headset would not cooperate. I also got REALLY motion sick during and after the assignment because the visuals the VR was providing made me think I was floating and it got confusing.	Absolutely. If we could do the entire class in VR that would be awesome (I just have to take some Dramamine first). The assignment was awesome and super educational.
It was kind of hard to see every piece of the brain because some of the structures were similar colors and difficult to see.	Yes, it was helpful.
Nothing was notably difficult, it just took a minute to learn to use everything.	Yes, I think it is beneficial to engage in active learning rather than solely passive learning.
Nothing really. It was very straight forward and easy to understand.	Yes! It very interesting and beneficial for reinforcing information.

Table 1. Feedback from students who endorsed a value of 4 or above to the question “Did you feel any discomfort during your experience with the system.

Aim 3: User perceptions.

Feedback from students was universally positive. Even students who reported difficulty with managing the software or experienced discomfort highly endorsed the learning value of the VR lab experience and would recommend it to be used in future classes (table 1). On a Likert scale from 1 (not at all) to 5 (very much so), the average response on all positively valanced questions exceeded 4. On the negatively valanced question (did you experience discomfort during your time in the system), the mean response was 2.32 (SD = 1.17; Figure 1). Qualitative feedback in the User Satisfaction Evaluation Questionnaire was reviewed for trends. Students were uniformly positive in their feedback. The most common issue raised when asked “What was difficult about the virtual reality assignment” was difficulty mastering the controls and orienting to the VR view. In response to the question “How did the virtual reality assignment help your learning” the dominant themes were the three-dimensional nature of the program, seeing how parts of the brain are connected, and the “hands on” approach to learning. Additionally, two students requested that the VR equipment and program be made available for studying outside of the assignment.

DISCUSSION

We were successful in completing the aims of the current study to assess the feasibility, utility, and perception of using VR software in undergraduate neuroscience courses. Partnership between the university library and psychology department allowed us to leverage existing infrastructure to provide a meaningful learning experience to students.

The initial concerns about the practicality of bringing 39 students into the library for appointments while COVID protocols were enacted we were able to schedule the appointments without surpassing the TA’s contracted 20 hours a week. Students were compliant in making the appointments using LibCal and no severe scheduling issues such as no-shows or forgotten appointments arose. This is most likely due to the novel and exciting nature of the assignment. Students were motivated to experience the VR room and were told many times that they were being given special access to library equipment.

The largest limitation to implementing this type of assignment in undergraduate neuroscience courses is lack of infrastructure and staffing. Although VR equipment is costly, there is a growing demand and availability of these resources (Jensen & Konradsen). Additionally, there are low-cost VR solutions that utilize smart phone technology, such as Google Cardboard and low-cost anatomy applications and 3D videos that may provide a similar student experience, although not as interactive as the Oculus or HTC systems.

There is considerable work that is involved in setting up and operating a VR room. Even with help, there are questions still remaining about what resources are needed to fully support its use for targeted class assignments such as this one. Currently, a single faculty librarian is managing the VR room and doing targeted instruction for faculty and students with 52 sessions with 209 participants (FY 2019-2020), but the room has been largely unstaffed except for circulation desk personnel that manage the checkout of the controllers. After completion of the current project, it is clear that more staffing is necessary to support classroom assignments that use the VR room in the future.

As highlighted by this classroom assignment, VR requires significant staffing overhead for student use, especially during in the initial introduction session. This is a major question at this early stage in VR’s adoption in education: What is the professor’s/department’s responsibility and what is “lab’s/library’s” responsibility for the staffing needs of an individual assignment? Ultimately, like any lab in the university, we expect that the university

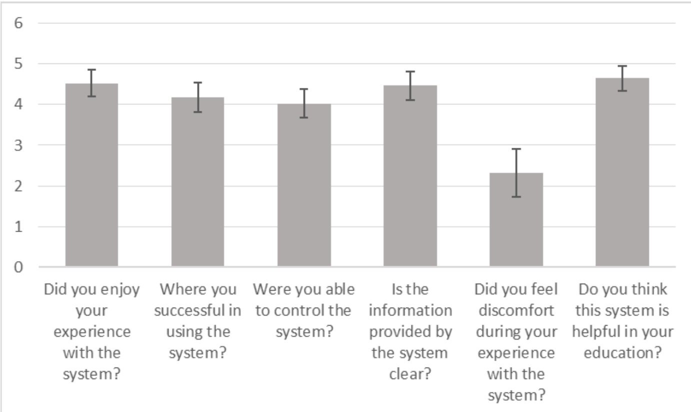

Figure 1. Mean responses to User Satisfaction Evaluation Questionnaire. Survey responses ranged from 1: "Not at all" to 5: "Very much so".

will consider funding this resource centrally and place it in existing VR rooms. But for now, individual departments and professors need to find ways to fund the continuing staffing needs of VR assignments.

Without a TA to manage the sessions as their primary job responsibility, it would have been difficult to implement this assignment. A work around to this issue may be having undergraduate students act as TAs for credit or independent study. Because the largest time commitment is demonstrating and supervising the VR equipment, not grading, this would be easily implemented in a peer-to-peer fashion. Future directions include creating a video that demonstrates use of the controls, navigating the program, and detailing how to take a screen shot that would be available to students before they make their appointment.

In terms of reaching student learning outcomes, we found evidence that students performed well on exam questions related to neuroanatomy. Similarly, students overwhelmingly chose to answer a short answer question about neuroanatomy compared to other exam topics, suggesting increased familiarity and comfort with the topic. Further research directly comparing learning outcomes after a VR neuroanatomy lab compared to actual dissection or other models is needed to further support that VR labs offer an equivilent or superior method of teaching neuroanatomy, but the current study does offer limited evidence supporting the hypothesis that a VR neuroanatomy lab impacted students learning outcomes in an undergraduate neuroscience course.

Finally, in terms of user perception, we found evidence that students unanimously endorsed the use of the VR lab in undergraduate neuroscience courses. This endorsement must be cautiously interpreted, as students may be responding to the perceived novelty of learning modality, rather than the actual effectiveness of the strategies (Clark, 1983). However, previous work on VR and gamification in the classroom, show that student buy-in is an important predictor of learning outcomes, regardless of the actual effectiveness of the strategies (Davis et al., 2018; Martin, 2014). Thus, even in the possibility that there is no actual benefit of three-dimensional VR dissection labs compared to computer models or textbook images, the perceived novelty by students encourages learning of course objectives.

In addition to the previously discussed limitations of time and infrastructure, it is important to note that one student was unable to complete the assignment because of nausea and claustrophobia, two students in their feedback mentioned that they experienced motion sickness, and another said they had a headache afterwards. It is vitally important that students be warned about the potential effects of VR headsets before completing the assignment and alternate assignments be made available. This type of motion sickness is common in VR environments and may affect women more than men (Chattha et al., 2020; Munafo et al., 2017).

Overall, we were able to complete the three aims of the study and found that incorporating VR labs in undergraduate neuroanatomy research was feasible using intrauniversity partnerships between the Department of Psychology and library. Additionally, we provided limited evidence that the VR labs increased student retention and comfort with neuroanatomy. Finally, we showed that students overwhelmingly endorsed the use of a VR lab in the course and that there was significant student buy-in on the use of this technology.

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APPENDIX
Virtual Reality Brain Dissection Lab Instructions

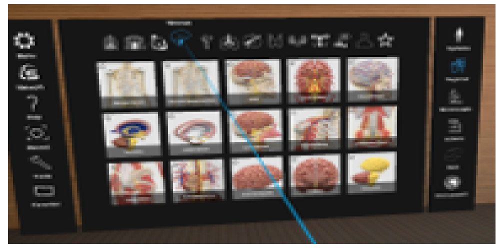
PSY 448
Virtual Reality Brain Dissection Lab
Fall 2021

1. Make an appointment at https://urlhere

2. Arrive at the Library Circulation desk to meet RA and walk back to the VR lab. Wear a mask.

3. Go through the orientation of how to use the equipment and open the Organon app. Get comfortable using the controls and mess around a little in the app. Try moving the skeleton up and down, removing different bones, etc.

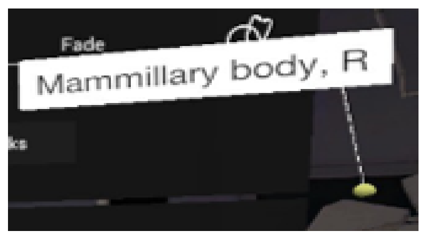
4. Using the hand controls select the regions icon. Then, find the nervous system icon which will then take you to the brain options. You will use the "cerebrum" option for #5 and 6. Then, you will switch to the limbic system view for #7. RA will be there to help guide you, but the picture to the right will give you an idea of what you will see. Once you get to the brain option, RA will run through how to move the brain up and down, bigger/smaller, forwards/backwards, and how you can turn the head in a 360 degrees.

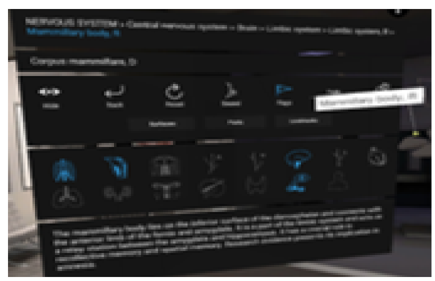


5. Select "cerebrum" and pull apart brain areas from left to right. Take a screen shot that exposes a sagittal view of the brain. Paste that image here:

6. Choose three structures and read the information on the blackboard side bar shown in the example below. Take screen shots of each structure and match the description to the image. List the structures, describe their position (using the anatomical terms we learned in class), and explain their function here:

Ex: This is the mammillary body. The mammillary body is in the anterior medial part of the brain connected to the fornix and the amygdala. This structure has a lot to do with recollective memory and the function of memory between the amygdala and the hippocampus.





7. Select the "limbic system" icon.

8. Take apart the limbic system slowly. Find the amygdala and hippocampus.

   a. What do you notice about their proximity?

   b. Are these structure unilateral or bilateral? What does that mean?

   c. Do you think they would be easy to differentiate in a real human brain? Why or why not?