DISSERTATION

EVALUATING CURRICULAR IMPLEMENTATION TECHNIQUES TO ENHANCE ANATOMY EDUCATION

Submitted by

Natascha Heise

Department of Biomedical Sciences

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Doctoral Committee:

Advisor: Tod Clapp

Jerry Bouma
Quint Winger
Kalpana Gupta

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ABSTRACT

EVALUATING CURRICULAR IMPLEMENTATION TECHNIQUES

TO ENHANCE ANATOMY EDUCATION

The need for healthcare workers in the United States is growing exponentially, and in order to meet this increasing demand, medical schools and other health-related institutions have begun to increase their student enrollment. Human anatomy is one of the foundational courses in medical school, and if students develop a good understanding of human anatomy, then they are more likely to be successful as a health-care professional. However, changes in the curriculum over the past several decades have decreased the time, faculty, and money devoted to the anatomical sciences. Therefore, it is of great importance that anatomists identify and implement methodologies that increase learning efficiency in the classroom which will ultimately aid students in their success. Previous mixed methods studies have started to bridge the gap between research and practice in science teaching to evaluate existing teaching strategies and incorporate more time efficient and active learning strategies. These studies have shown that students gain a greater amount of knowledge, are more engaged, and acquire an abundance of skills if the teaching methods are purposefully incorporated into their anatomy curriculum. Most of these curricula are guided by the influential work of Plato, Immanuel Kant, John Dewey, Malcolm Knowles, Allan Bloom, David Kolb, and Howard Gardner, whose theories have been used in the social sciences for decades.

The goal of this work was to evaluate existing methods and the implementation of novel pedagogical techniques in the human anatomy and neuroanatomy classroom at Colorado State University, purposefully implement new time efficient teaching methods, and make recommendations for educators of the anatomical sciences and other disciplines. It identifies important and practical strategies for increasing

efficiency in the classroom to improve student mastery of human anatomy in less time. A mixed methods approach was used in these studies collecting both quantitative and qualitative data, providing an in-depth view of how the research participants experienced the implemented curricular changes in the classroom. This methodology shed light on the benefits and implications of the different pedagogical implementation techniques.

Chapter II reviewed the use value of low-stakes frequent quizzing in a cadaveric laboratory. The aim of this study was to investigate the relationship between weekly table quizzes and the overall student outcomes in a graduate biomedical human dissection class, as well as to examine the benefits and implications of this approach. The data suggested a potential correlation between performance on weekly quizzes and on unit examinations. This uniquely structured assessment tool provided the students with the opportunity to practice the retrieval of their knowledge, feel more guided throughout their dissection, and receive immediate feedback on their performance. Chapter III investigated the role of technology in anatomy education, specifically examining learner engagement and retention utilizing Virtual Reality. Results suggested that using Virtual Reality was comparable to two-dimensional methods in student knowledge acquisition and retention of anatomical relationships, and qualitative data collection indicated that the technology promoted student engagement and increased opportunities for students to interact with teaching assistants, peers, and the content. The purpose of the studies in Chapter IV was to investigate how a semester-long group project in a cadaveric graduate classroom at Colorado State University and Rocky Vista University affected students' group dynamic, personal development, experience, and learning approach. Results indicated that the majority of participants (85%) underwent a change in their development as a group member and have modified their learning strategies from rote memorization to being able to connect the material as a whole. The use of case studies in an undergraduate classroom was investigated in Chapter V with the hope to improve student confidence and provide them with a definitive useful road map when solving any novel problem. Results indicated that student performance on written case study summaries improved over approximately ten weeks of practicing the systematic four-step approach. Further, students reported that the approach greatly increased their confidence in tackling a novel problem.

Chapter VI provides a teacher's manual explaining the detailed use and application of the approach in the classroom while using the neurological condition hydrocephalus as an example. Chapter VII focuses on the design, implementation, and evaluation of a full-time, week-long human anatomy camp at Colorado State University. Success of the program was measured by a follow-up survey one-year after camp, indicating that all 28 senior high school students had applied to college and were considering STEM as a career path. Camp counselors have reported continued mentor/mentee relationships with the students after camp. This study further evaluated the use of case studies in the classroom and as a way to work and connect high school with college students.

Overall, these studies address effectiveness of anatomy education at the undergraduate and graduate level through in-person, remote, and outreach instructional methods. The findings in this work suggest that anatomy education should include frequent low-stakes quizzes, technology, long-term group work, and problem-based learning methods to shift to more effective and active learning in the time restricted classroom. These studies recommend consistent evaluation of existing teaching methods through the lens of evidence-based learning theories and will inform educators in the anatomical sciences and other disciplines on practical methods to supplement or substitute existing teaching practices.

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DEDICATION

I would like to dedicate my dissertation to my father Wilfried, my mother Sybille, and my sister Sarah.

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CHAPTER I – INTRODUCTION

1.1. PURPOSE

There is an exponentially growing need for healthcare workers, with global demand estimates reaching 80 million healthcare workers by 2030 [1]. The health care workforce is composed of a wide variety of professions whose job is to protect and improve the health of their community. This workforce includes physicians, physician assistants, dentists, occupational therapists, pharmacists, physiotherapists, registered nurses, as well as medical laboratory scientists, social workers, and many others. To meet increasing demand, medical schools and other health-related institutions in the United States have started to increase their student enrollment [2-3].

The four-year traditional medical school curriculum is comprised of two years of basic sciences followed by two years of clinical rotations. Human anatomy is offered in the first year of medical school and forms one of the foundational courses for success in healthcare. A comprehensive understanding of how anatomical systems interact with each other enables health-care professionals to better diagnose and treat patients. It is therefore of importance that students receive an education in human anatomy of the highest standard throughout the United States. Additionally, many undergraduate and graduate students enroll in human anatomy coursework to learn more about the human body out of interest or to prepare for future career paths.

Nevertheless, recent changes in human anatomy education have resulted in less time, less faculty, and less money devoted to the anatomical sciences. Since the 1990s, medical schools in the United States have revised their curricula towards a more student-centered instruction [4-8]. In a 2014 study surveying 55 programs within the United States, all programs had changed their curriculum to either a partial or fully integrated curriculum connecting subjects such as neuroanatomy, gross anatomy, microscopy, and embryology. Many medical schools have moved away from lecture-based methods and some even completely eliminated traditional anatomy lectures [9-12]. Though these changes have promoted students' ability to apply anatomical concepts to a variety of scientific disciplines, increased self-directed learning demands have resulted in smaller amounts of time devoted to each individual concept. This adds additional pressure to anatomists to identify methodologies that increase learning efficiency and satisfy learning outcomes [13].

With the aforementioned changes in the curriculum decreasing money, time, and faculty dedicated to the anatomical sciences, anatomists are now challenged with how to be creative in the delivery and assessment of their content and use their time with the students more efficiently. This led me to the following overarching research questions: How can we evaluate existing teaching methods in human anatomy curricula? How can we implement more time efficient teaching methods in the human anatomy and neuroanatomy classroom? And how can these results inform future curricula and educators of other disciplines? Using these questions as a guide, this work will identify important and practical strategies for increasing efficiency in the classroom to improve student mastery of human anatomy.

1.2. METHODOLOGY

The studies discussed in the following chapters follow a mixed method research design. The term "mixed methods" refers to "an emergent methodology of research that advances the systematic integration, or 'mixing,' of quantitative and qualitative data within a single investigation or sustained program of inquiry" [14]. The goal of mixed method studies is to integrate quantitative and qualitative data collection and analysis to enhance the research findings [15]. Quantitative data is commonly composed of measurable information and is analyzed through numerical comparisons and statistical interferences [16]. Qualitative data is descriptive and is collected through observations, open-ended survey questions, individual or focus group interviews [16], as well as related textual and visual media and artefacts [17]. Combining both types of data collection can help refine existing research questions, generate a hypothesis, and help identify variables important for the study.

Mixed methods research originated in the 1950s in the social sciences but became a formally recognized research method in the late 1980s [18-20]. Over the past years, its approach and analysis has been refined in order to suit a variety of research questions [21]. Despite 30 years of widespread use in other disciplines, scholars have found that scientific researchers are still relatively unfamiliar with mixed methods research design and struggle to incorporate mixed methods in evaluation of existing curricula [22]. In clinical and health-related research especially, researchers primarily rely on quantitative measures in the form of controlled trials and focused hypothesis-testing [17] over qualitative research methods. This might be due to the lack of training using both quantitative and qualitative methods, time, and resources needed to conduct a mixed methods study [23], and existing resistance to implement and evaluate novel teaching methods in the scientific classroom [24-27].

In addition, this methodology is not commonly used in the scientific classroom due to widespread misconceptions of this approach. Common misconceptions of qualitative research include a perceived lack of reliability, validity, and ability to generalize research findings [17]. Such criticisms fail to acknowledge that qualitative research is based on purposeful sampling to test a particular theoretical premise. Individuals with specific characteristics are chosen from the general population in order to investigate a specific question [28], which permits a detailed examination of the phenomenon rather than a statistically generalizable [17]. In terms of validity, quantitative research focuses on replication to verify findings. Replication is rarely possible in qualitative research, except when triangulation is incorporated into the study methods [17]. Multiple researchers analyzing the same data independently and looking for outliers that do not align with prior predictions [17], can result in a more accurate interpretation of the phenomenon.

When incorporating research findings into science teaching, it is important to evaluate if the combination of quantitative and qualitative data enhances the data collection and overall outcome of the study. Hurmerinta-Peltomaki and Nummela propose that mixed methods add value by increasing "validity in the findings, informing the collection of the second data source, and assisting with knowledge creation" [29]. Others claim that that this methodology is necessary to explain all perspectives in a study [30]. The

‘What?’ and ‘How often?’ is the primary focus using a mixed method approach as it describes a phenomenon and attempts to measure how often an experience occurs [17].

Recently, educational research has gathered more attention in the health and medical field [14] and has been used to overcome current learning barriers and improve existing teaching methods. Qualitative methods have been increasingly recognized as an effective tool to explore complex phenomena in scientific classrooms that are difficult to assess using only quantitative methods [17,31]. Following is a review of scientific studies demonstrating the success of using both qualitative and quantitative educational research to evaluate existing teaching methods in the cadaveric laboratory and supplemental materials used in the anatomical sciences curriculum. Educators have started to implement various tools to not only use the time more efficiently, but also to improve student performance in anatomical courses, deepen their understanding, and increase long term retention of the material.

1.3. LITERATURE

1.3.1. Cadaveric Laboratory

In the cadaveric laboratory, educators have started to evaluate a dissection versus prosection cadaver approach, the use of weekly assessments, small group learning environments, and incorporation of clinical correlations in order to teach human anatomy.

1.3.1.1. Dissection versus Prosection

At some institutions in the United States, undergraduate students have the opportunity to enroll in prosection-based anatomy courses, in which they interact with and learn from fully dissected cadavers. Some graduate courses have shifted to a full cadaveric dissection, similar to medical curricula to better prepare students for future careers in healthcare. With the amount of shrinking time allotted to anatomy education in both medical school and graduate education, it remains debatable if a full-body dissection experience retains its value [32-35] or if cadavers should be used at all outside of medical schools [36-44].

On the contrary, some programs consider that a complete cadaver dissection constitutes the best method to learn gross human anatomy [34,45-46] and that all students should be exposed to that teaching method.

Patel and Moxham found that 69% of the anatomists they interviewed selected dissection, followed by prosection, as the most appropriate and effective teaching method [47]. Learning through dissection presents several significant advantages, including active and deep learning, preparation for future classes, handling encounters with death, manual skills, and understanding the relationship between symptoms and their pathologies. Dissection further enhances the development of professionalism by promoting teamwork competency, stress coping strategies, and empathy [46,48-50]. It also simulates an operating room in that allows for the exploration of anatomical variations and texture of the dissected structures [51]. While these benefits are certainly well established anecdotally, their intangible nature makes them difficult to quantify.

Other institutions find that facilitated sessions with prosected cadavers paired with some dissection accomplish similar outcomes more efficiently and effectively [52-58]. A retrospective study at Western Michigan University School of Medicine in Kalamazoo Michigan examined the effectiveness of learning regional anatomy through dissection versus prosection methods measured by students' retention on anatomical knowledge [35]. These assessments were composed of a teaching-readiness quiz, a summative test of multiple-choice questions, and a practical examination. Student test scores on these assessments were compared between those who dissected and those who learned from prosected specimens [35]. Data suggested that anatomy knowledge was equivalent, regardless of the instructional method, during all three assessments. However, prior anatomical knowledge had a great impact on the knowledge retention. In general, prosection offers more flexibility, easy observation of structures, identification of more anatomical structures, less time needed in the laboratory, and overall fewer cadavers are needed, as more students can work on the same cadaver at different times [59-62].

Overall, prosection appears to offer more benefits in student learning while remaining an efficient use of limited student time [62-63]. However, dissection provides an unparalleled hands-on experience and an opportunity for the students to gain valuable skills that are difficult to quantify. Several factors must be taken into consideration when deliberating over which format to select as appropriate for any given institution, including student hours in the laboratory, overall course load, number of donated bodies, financial constraints, and number of faculty and staff present in the laboratory [60]. Even with these considerations, exam performance remains the major driving force in curriculum development for some programs, however this should not be the only factor in determining if dissection or prosection is beneficial. Institutions should critically evaluate which approach would suit their curriculum the best as there are intangible benefits in using either method.

1.3.1.2. Weekly Assessments

Studying the anatomy of the human body requires constant memorization and application of knowledge in order to solve novel clinical problems. In many medical and graduate human anatomy courses, students are exposed to independent, self-directed work to acquire an extensive understanding of the human body and to develop skills beneficial for their future career. Some students struggle with that lack of guidance, as many undergraduate courses mainly focus on rote memorization of the presented material. This problem is further compounded if the course does not offer a lecture component due to time constraints. With the high course load medical students face, it is important to maintain motivation and engagement, even in more complex and difficult tasks. Scientific and educational literature agree that frequent, interactive quizzing positively correlates with student outcomes, which aids in the difficulty associated with independent learning [64-65]. Incorporating regular assessments into different learning environments helps to engage students, enhance learning [66], maintain motivation, promote more frequent review of content, and enable student-teacher interactions [67-68]. When comparing multiple-choice versus short answer testing formats, studies indicated that regular short answer quizzes paired with feedback are more effective in enhancing student learning than a traditional multiple-choice format [69-70].

Checklists have also been used by many institutions to evaluate learning in a gross anatomy laboratory and to improve dissection quality [71]. An example of the use of these interactive weekly quizzes was reported by Ettarh at Tulane University School of Medicine in New Orleans Louisiana [72], in which weekly quizzes, called table conferences, were implemented into a histology anatomy class. Between 2011 and 2015, 711 medical students were either enrolled in a traditional laboratory-based course (n = 353) or a team-based hybrid course in which interactive table conferences were implemented (n = 358). These conferences required the students in the hybrid course to work in teams, review images, solve problems, and share their learning. Outcomes of the National Board of Medical Examiners (NBME) showed significant improvement in test scores. The interactive table conferences helped the students to use their time in the laboratory to learn independently, review the material more frequently, and to form the important connections between the laboratory and the clinical facts learned in lecture [72]. However, the overall goal of this study was not to improve student outcomes but to increase the frequency of content review and to increase the interaction between peers and with faculty. In another anatomy course at Mayo Medical School in Rochester Minnesota, students reported that they perceived similar weekly assessment of their dissection as a "valuable and rewarding part of their anatomy course." In addition, 64% of students agreed that the evaluation of their dissection in the form of weekly quizzes helped them to use their laboratory time more efficiently [73]. In this study, quality of dissection was evaluated biweekly using a rubric based on learning objectives. Assessment of anatomical knowledge was based on practical examination scores as well as quizzes. Students (n = 48) broken into twelve teams were included in the study and results indicated a positive correlation between dissection quality and practical examination scores (R = 0.83).

Contrary to these results, feedback from students in a similar study revealed that students were not enthusiastic about the quizzes [74]. In this study at the University of Texas Medical School in Houston Texas, 21 incoming medical students took six anatomy quizzes of about 50 questions during a short pre-entry program in the summer before official enrollment. Each quiz was self-paced and lasted about 30 minutes. 50% of the students thought they were helpful, 12.5% were undecided, and 37.5% did not find them helpful. Students would have liked the quizzes to be shorter and in multiple choice format such as those used in their written examinations rather than fill in the blanks [74].

Problem solving is a more complex and detailed skill that requires a more guided instruction [75]. Weekly oral quizzes and checklists may provide that guidance in the cadaveric classroom. This and other studies reported that the implementation of those assessments kept students motivated and guided them throughout their dissection [76]. Implementing these low-stake frequent quizzes provided the educators with the opportunity to interact with students and test their knowledge in a time-efficient manner. Nevertheless, more educational studies are needed to explore all benefits associated with weekly quizzes in the cadaveric laboratory.

1.3.1.3. Group Work/Peer Learning

Working with cadavers is an expensive undertaking due to high transportation, preservation, and storage costs. As a result, most cadaver-based anatomy classes assign students into large groups working closely on one cadaver independently from faculty and staff. Some institutions focus on self-directed group learning whereas others underline the presence of teaching assistants in the laboratory. The benefits of collaborative learning have been well documented in a variety of disciplines [77-80], including anatomy curricula [81-86]. Reported benefits include active learning [79], efficiency in terms of faculty to student ratios [83], students taking responsibility for their own learning [82], and improved student outcomes [82]. Further, group work and peer teaching with cadavers provides the students with the opportunities to develop hands-on, communication, and leadership skills [87].

A study at the University of Ottawa in Canada medical program compared independent learning with facilitated small group learning in the anatomy laboratory. In the “facilitated active learning approach” (FAL), tutors engaged with the students and were expected to facilitate active learning and progression through specific objectives in the prosection laboratory [88]. The tutors facilitated discussions by posing questions that were previously presented in a one-hour training session before the laboratory. The other approach, the "emphasized independent learning" (EIL) approach, followed a flipped classroom model during which students prepared the content on their own and independently worked in the laboratory with minimal tutor involvement [88]. Tutors were instructed not to interfere when working with prosected cadaveric specimens and were only a resource to clarify points of confusion. Results indicated that FAL students significantly outperformed EIL students in their practical examination in anatomy (FAL: 82.73% ± 0.95 vs. EIL 76.79% ± 1.52; $p < 0.001$) as well as during knowledge application questions during those examinations (FAL: 76.28% ± 1.29 vs. EIL 68.26% ± 1.76; $p < 0.001$). Both approaches were perceived by students to enhance professionalism and promote active learning to similar extents. FAL students were more likely to finish all learning objectives, yet active learning and student engagement was highly dependent on the tutors. EIL students were frustrated with the learning efficiency and lack of direction and feedback from tutors regarding questions, but the learning environment enhanced independent learning skills, communication, and collaboration [88].

This approach has shown that there are both advantages and disadvantages to having tutors or teaching assistants present. However, having students work through the prosection laboratory together in groups may be helpful in developing group problem solving and communication skills, both of which are valuable for students who are looking to become physicians [84,86,89-90]. Related to the practical examination, tutors demonstrated an important aspect in helping the students succeed. This and other studies underline the importance of teaching assistants in the laboratory to aid students in their dissection and learning [91]. This approach may overcome the problems students face in anatomy when no lecture component is present. Nonetheless, more qualitative data is needed to explore all benefits and disadvantages associated with group work in the cadaveric laboratory. Differences in group sizes might affect their time in dissection, their learning experience, how they retain the material, study habits, and their overall perception of learning human anatomy.

1.3.1.4. Building Clinical Correlations

Medical students are required to develop good clinical reasoning skills, but often struggle to connect foundational science training (basic anatomy, physiology etc.) to clinical scenarios presented later in their curriculum. It has been suggested that medical education should be structured to encourage learners to form links and relationships between clinical facts and other basic science concepts [92-95]. Therefore, many medical schools have started to move away from isolated, discipline-based courses and are using a system-based approach to integrate more clinical content into their foundational coursework [7,96-100].

According to Klement and colleagues [101], "clinical correlation" is defined as a learning tool that enables the students to apply a basic science concept to medical practice or a disease which can be implemented in many forms in the classrooms and laboratory. Klement proposed the use of clinical correlations in order to blend both concepts together and promote learning, association, and translation of basic science information into clinical relevance [101]. Problem-based learning (PBL) follows similar principles. However, in this particular study, clinical correlations focus mostly on applying basic scientific content to cadaveric laboratories whereas PBL focuses primarily on developing problem solving and analytical skills in a traditional classroom setting. Klement acknowledged that lectures are a time-efficient way to deliver content but noted that other teaching formats are more effective in making connections between basic science and medicine [101].

In this particular study at the Morehourse School of Medicine in Atlanta Georgia, students worked in groups to solve basic clinical problems during their laboratory and lecture time. These exercises included correlated examples in which the students were presented with a short story that related to a disease, given demonstrations and interactive learning, allowed specialized hands-on laboratory sessions, and given small-group activities [101]. All of these clinical correlations assisted in preparing students to evaluate patient medical histories, develop diagnoses, and select appropriate diagnostic tests in a lecture or laboratory setting. Some activities required the students to extensively prepare in advance, whereas in others, students only participated in simple activities. These groups were supervised by faculty who provided feedback on their progress. Improvement in course grades and clinical reasoning skills has been seen in other studies after implementing clinical correlation activities into their courses but it is hard to determine which elements promote knowledge retention [101]. However, this study review was not experimental and did not focus on measurable outcomes as it only described potential curricular implementation techniques in order to incorporate more clinical information.

Overall, this format of connecting basic science with clinical content can be used in the cadaveric laboratory as well as in lectures to enhance the transfer of knowledge and linking different subjects [101]. This allows the students to focus on understanding of the basic science content first before diving into clinical rotations. Not many institutions have implemented this or a similar approach, which illuminates a need of further data evaluating this concept.

1.3.2. Cadaveric Substitutions

Outside the cadaveric laboratory, institutions have implemented and evaluated the use of plastinated specimens, physical models, case scenarios, and computer-assisted learning programs to substitute donated cadavers in their anatomy classroom.

1.3.2.1. Plastination/Physical models

The study of anatomy is mainly concerned with identifying anatomical structures and understanding spatial relationships among them [102]. Two-dimensional (2D) imaging of anatomical structures, however, makes it challenging for students to visualize anatomy in three-dimensions (3D).

Plastinated specimens and physical models represent two cost-effective alternatives for both studying the human body in 3D and increasing spatial awareness. These approaches have already been in use in some undergraduate and medical classrooms, as well as in K-12 classes.

Plastination is a preservation technique using silicone resins or epoxy polymers and was first developed at the Anatomical Institute of Heidelberg University in Germany by Gunther can Hagens in 1977. Since then, it has become one of the most popular techniques for the conservation of the human body [103]. It is particularly beneficial since additional prosections only need to be done every ten years; however, it does use large amounts of chemicals that create health and safety concerns. Plastination can also be problematic in that it can cause shrinkage of organ tissue and loss of texture, color and fine details, making it harder to study anatomy realistically [48]. Additionally, many anatomists prefer using plastinated specimens over formalin fixed. This is because they are odorless, easy to handle and easy to store, as refrigeration and fume extraction are not necessary [50,104-105]. Studies have shown that plastinated specimens have a value in the depiction of structures [106], were deemed useful by students, and provided a novel learning opportunity [50,104]. Despite their potential educational value, the use of plastinated specimen in the anatomy curriculum and reported benefits mostly come from studies outside the United States including Germany, Austria, France, Bulgaria, China, and New Zealand [107]. It is currently unknown how many U.S. institutions utilize or generate plastinated specimen.

A study at the University of Murcia in Spain evaluated the use of plastinated specimens in the veterinary and human anatomy curriculum [104]. During the scheduled laboratory session, the control group worked with wet organs and anatomy sections preserved with classical fixative solutions. Wet organs are generally tissues removed from a cadaver and stored in 70% ethanol with various additive after fixing with formalin or a salt-solution. Students in the experimental group used only plastinated specimens, but both groups were able to work with instructors who demonstrated and explained the anatomy. Pre-test results showed that both groups started with a similar level of knowledge. Statistically significant differences were observed in the post-test knowledge of both groups, showing that the group working with wet organs scored statistically significantly higher. The experimental group stated that they found the plastinated organs useful and instructors believed that this tool should be used to complement the dissection experience [104]. In contrast, Warwick Medical School in the United Kingdom has recently replaced wet cadaveric specimen in their undergraduate anatomy classroom with plastinated prosections entirely [50]. This mixed-methods study utilized a questionnaire and focus group interviews. Of the 125 participants, 94% rated the plastinated prosections as a valuable resource, as they showed a detailed view of the anatomy and structural relationships. However, students reported that they preferred a more tactile and emotional experience, so plastinated structures were seen as a compromise. The study concluded that plastinated prosections may be a good resource during undergraduate training, but wet cadaveric material should be used in professional school in order to expand the anatomy experience [50].

Physical models as a 3D learning method is still of interest in the anatomy classroom as they can supplement traditional instructional methods. Previous studies have shown that the use of models is superior to 2D images in the teaching of complex anatomical areas such as the larynx and knee [108-109]. Studies further showed that students using anatomical models demonstrate significantly better results in 3D visualization and understanding of cross-sectional anatomy over students working with 2D images [110-112].

One such study at Sungkyunkwan University School of Medicine in Korea incorporated clay models into their gross anatomy and neuro-anatomy courses [110]. Half of the second- and third-year medical students (n = 20) were required to make clay models of organs, cut them transversely and compare them to CT and MR images during their anatomy class. The other twenty students formed the control group and only studied two-dimensional CT and MR images. The students using the clay models were generally satisfied with the learning experience as it helped them to understand the 3D structures and cross-sectional anatomy more easily after they had built, cut, and compared them with images. They scored significantly higher on their CT examination compared to the control group (70% and 50% respectively). Six months after completion of the course, the second CT examination revealed no significant difference between the two groups. This showed that clay modeling may not be an effective learning technique for long term retention and knowledge about cross-sectional anatomy, but it was an effective tool at the time of instruction [110]. Similar results were found at Boston University School of Medicine in Massachusetts, which used constructed 3D color-coded physical models to supplement their 2D brain cross sectional instruction in the neuroanatomy curriculum for first year medical students [111]. The experimental group (n = 51) working with the physical models scored higher on the quiz questions that required a 3D visualization but not on the 2D images as compared to the control group (n = 50). Of all students, 84% recommended using the models for future laboratories.

A meta-analysis by Yammine and Violato has shown that educational methods using physical models yielded significantly better results in overall knowledge outcome, spatial knowledge acquisition, and long-term retention when compared to other methods [102]. Their analysis included eight studies within the US, UK, Canada, and South Korea with a total of 498 learners composed of undergraduate, medical, and nursing students. Although no significant improvement was found in terms of factual knowledge acquisition, the learners' perception of the use of physical models was generally positive [102].

In conclusion, physical anatomical models and plastinated specimen offer viable alternative tools for teaching gross anatomy in 3D due to its easy access, low costs, and educational effectiveness. These substitutions also may contribute to increasing knowledge and understanding of structural relationships.

1.3.2.2. Problem-Based/Case-Based Learning

There is an increasing emphasis in academia on finding pedagogical approaches in the classroom to encourage critical thinking. While the ability to recall information is helpful in forming basic knowledge, it does not prepare students to solve novel problems [113]. Students, particularly those interested in the health fields, should be able to apply their knowledge and form a differential diagnosis when faced with a patient's complaints. Classrooms using the Problem Based Learning (PBL) approach follow a more student-centered pedagogy involving a dynamic classroom, with a goal of letting students acquire a deeper knowledge through active exploration of posed problems [114-115]. Literature describes PBL as a process of inquiry, a learning-to-learn approach, and a method for acquiring new knowledge [116]. It consists of the following elements: 1) groups of students are exposed to a medical scenario or case; 2) an instructor facilitates learning; 3) students experience self-directed learning; and 4) students engage in a problem-solving process [117-119]. PBL focuses on developing problem solving and analytical skills and was developed at McMaster University in Ontario Canada in order to help medical students learn to integrate their learned information [120]. In PBL, students define their own learning outcomes in relation to the problem. The use of case scenarios has become a popular tool in those PBL classrooms to encourage critical thinking and increase engagement [121]. PBL is similar to case-based learning (CBL) as both approaches make use of clinical cases. However, in CBL, students are guided and learning outcomes are more defined. In most medical institutions, CBL and PBL classrooms are blended and hard to differentiate. Observed benefits of using PBL in anatomy classrooms are an improvement of student's ability of independent innovation, cooperation and communication among the students, and the ability to combine theory with practice [122]. Further, a study by Heijne-Penninga et al. indicated that students exposed to student-centered PBL curricula showed an increase in long-term knowledge retention compared to students in a more traditional, teacher-centered curriculum [123].

Case scenarios used in PBL include clinical cases, patient histories, situations of medical importance, or real-world concerns related to human anatomy and physiology [124]. At Niagara University in New York, Cliff exemplified this by implementing case studies in an undergraduate anatomy and physiology class. Students were given cases with tables of data or figures that drew upon knowledge of anatomy and physiology combined with ten to fifteen questions. Outside of class, the students completed a case analysis in groups. Based on their responses, 70% of the students provided positive feedback about their experience and Cliff suggested that this approach not only improved the depth and ease of learning, but also increased curiosity and appreciation of the relevance of the underlying anatomy [124]. The cases formed a practical study aid and promoted reinforcement of the learned material, which was demonstrated in improvements on in-class examination scores [124]. In contrast, a more recent study compared a traditional course with an integrated problem-based course offered at two medical schools in England. Students taught on a traditional lecture format had higher scores in the basic science examination than the others one year later [125]. This suggests that students taught via lectures have a higher level of anatomical knowledge as opposed to students exposed to an integrated course. Similarly, Al-Madi and colleagues compared didactic lectures and problem-based learning methods in a hybrid dentistry class at Princess Nourah Bint Abdulrahman University in Saudi Arabia and observed a statistically significant improvement in knowledge and self-reported confidence using both methods [126].

In summary, some medical schools have successfully made use of case analyses in their teaching in order help their students enhance their problem-solving skills as well as "spice up the semester and show students how their esoteric learning impacts on the world" [121,127]. Even undergraduate classes have started to implement case studies into their science classes, which often showed positive results [113,124]. Thus, it can be concluded that providing real-world relevance may contribute to enhancing motivation for continued learning. However, guided instructions appeared to be necessary as students tend to skip, ignore, or casually read instructions if the instructor does not emphasize them [124]. It is important for students to be able to retrieve basic science knowledge in order to solve these novel problems. Students missing that knowledge may not succeed in working on case scenarios nor form critical thinking skills. Using case studies in human anatomy can be a time effective teaching method paired with flipped classroom instructions in which students prepare and acquire the basic science knowledge on their own and apply it in the classroom. This method would help those institutions which have eliminated traditional anatomy lectures, although not many institutions have implemented this or similar approaches, which creates a need of further data evaluating this concept.

1.3.2.3. Computer-Assisted Learning

In addition to knowledge acquisition, learning human anatomy has also been found to include spatial components [128]. Literature has previously shown that students with higher spatial abilities perform better on practical (cadaveric) examinations, 3D mental creation of a 2D image, and cross-sectional understanding [128-130]. Most students, however, struggle with visualization 2D images in 3D. Therefore, it is important to investigate novel methods of improving student spatial abilities. For this reason, computer-assisted learning is gaining more and more popularity in the medical curriculum. This form of instruction can be implemented into the anatomy curriculum in many forms; two examples being the use of anatomical programs and VR. The role of technology in anatomy education has yet to be precisely defined but appears to be increasing with the development of more virtual programs.

Anatomy programs use 3D models to allow students to visualize complex anatomical structures that can supplement teaching programs with limited staff and cadaveric resources. Although it is traditionally recognized that the use of human cadavers in hands-on laboratories is the most efficient way to learn human gross anatomy, the "versatile functionality and lightweight form" [131] 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. With the technological advances that our society is experiencing, our ability to access new information and increase the scope of education are expanding rapidly, making it possible for students to experience anatomy in more affordable ways. Examples of popular anatomy programs on computers include Netter's 3D Anatomy, Primal Pictures, A.D.A.M Interactive Anatomy, VH Dissector Pro, and many others.

Brucoli and colleagues detailed the benefit of using the Anatomage Table in preparing for a particular surgery which involved complex maxillofacial anatomy [132]. In order to come to the conclusion that the program was useful in preparing for and understanding maxillofacial surgery, an experiment was conducted at the Novara University Hospital in Italy in which the CT scans of fifteen patients with orbital floor fractures requiring surgical placement of titanium mesh were uploaded into the Anatomage Table and assessed by young surgeons and surgery residents. The individuals who worked with the program were surveyed after planning and performing surgical intervention and it was concluded that they all found the program to be helpful in providing clarity of dissected images as compared to that of the CT scans alone. It was stated, "in our opinion, the Anatomage Table can help young and inexperienced surgeons to practice on a cadaver, or a practice 'surgical dissection,' if you will, to prepare for peculiar clinical situations" [132].

Students have provided mixed reviews on their experiences with new 3D approaches to anatomy education. In one study, two groups of first-year medical students at the University of Thessaly in Greece, both without prior formal anatomical education, were evaluated after learning upper limb anatomy either in a traditional classroom setting or through the BioDigital Human software [133]. Half of the students (n = 40) attended lectures and cadaveric prosections in the laboratory and the other half (n = 32) attended lectures and worked with the BioDigital Human software. After completing the same examination ten days after the laboratory sessions, the study found that students using the software received higher scores (specifically in tagged structures) than those who learned via prosection techniques. At the end of the course, students were surveyed on their satisfaction with the course and the teaching methods they had received, and no statistically significant data was found on the favorability of one method over another. In summary, students using the BioDigital Human software performed better overall in the upper limb portion of the anatomy course and were equally as satisfied with the participation in the class as those students who did not use the 3D software [133].

VR has also been shown to be a viable learning tool for learning human anatomy. 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 [134]. Using head tracking information to calculate viewing angles and allowing users to simply move their heads to get another perspective was likely the original 3D interaction technique. In the last fifteen years, we have seen improvements in tracking and display, including reduced latency and increased accuracy in location and position tracking. These improvements led to the popularity and availability of VR-capable personal computers and the expanded use of virtual reality programs in areas of study such as anatomy education, neurosurgery, quantum chemistry, geology and many others [135-138].

Similarly, a study in Brazil at the University of São Paulo concentrated on using interactive and stereoscopic resources to teach neuroanatomy [139]. A stereoscopic image, also referred as 3D imaging, is the process of two photographs of the same object, taken at slightly different angles, are overlaid, creating an illusion of depth in the image. In this study, 40 human brains were dissected and placed on a manual-spin turntable platform. Images were taken and processed with VR Worx 2.6 software which arranged the pictures into a grid allowing for interaction with the dataset. Medical students ($n = 84$) underwent a pretest on the limbic system to assess their prior knowledge and then three groups were formed: Group 1 formed the conventional method group which attended lectures and looked at 2D images in a single-angle view. Group 2 engaged in interactive non-stereoscopic learning methods using VR. Finally, group 3 was instructed by interactive stereoscopic lectures with VR [139]. Groups 2 and 3 showed the highest mean scores in the theoretical examination, which was significantly different from those of Group 1 ($p < 0.05$). The method presented a gain of knowledge using VR when compared to traditional lectures and 2D images.

Küçük and colleagues from Ataturk University Medical School in Turkey used a mixed method approach to determine the effects of learning anatomy via a mobile augmented reality technology (mAR; 140). In augmented reality (AR) technology, the real environment is used as a background and a feeling of reality is created by adding pictures, animations, sounds pictures, or objects [141]. In this study, the researchers created a MagicBook that was available for second year medical students on their mobile devices in order to study neuronal pathways. In order to create this book, Axiom Neuro, Neuromatiq, and Anatomy 4D softwares were used combined with the printed book with Aurasma application which provides the tools to create all categories of AR experience. Students loaded the application on their mobile devices and were then able to use the multimedia materials. The experimental group worked with mAR multimedia materials consisting of 3D video animations, a 3D human anatomy model, and diagrams. When the students used this application while looking at pages of the book, they could see multimedia materials appearing on the mobile device scene. During the study, instructors used 2D images in two-to-three-hour lessons with the control group (n = 36) and mAR multimedia materials as well as 2D images with the experimental group (n = 34). After the two lesson sessions were completed, the experimental group was able to further use the MagicBook while the control group students reviewed the traditional book. A pre-test ensured that these two groups had statistically equivalent abilities. Results indicated that the experimental group had higher achievement levels in the 30-question multiple-choice test and lower cognitive load in comparison to the control group. In summary, the mobile learning approach helped students to learn anatomy in a different way by using less cognitive effort [140].

Another way of using VR in an educational setting is as a tool within medical training, as many students struggle through the process of knowledge transfer. The Faculty of Medicine at the University of Jordan created both a 3D heart model in VR as well as a physical model to compare a technological approach with traditional medical teaching modalities [142]. Medical students in their third year (n = 60) were able to manipulate and dissect the VR heart model as well as explore additional information of the structures and functionalities in the system in a semi-immersive environment (projector wall) wearing active stereo 3D glasses. The brief description of each structure allows the user to obtain theoretical knowledge while navigating through the system and associate this knowledge with the practical experience of dissecting the heart. The same students were also required to work with physical models of the heart. A comparative questionnaire contained 23 five-point Likert scale statements asking the students to rate their experience in using the physical models as well as the VR Anatomy System experience afterwards. The results showed high mean scores for the students' experience with the VR system and low mean scores for the students' experience with the physical model. Overall, this study focused on measuring the efficiency of the VR program in comparison to the physical model which was solely based on feedback through a questionnaire [142]. The results of this study underlined the potential of using novel technology in medical education, as it aids in visualizing complex anatomical structures and their relationships.

Computer-assisted anatomy programs have significantly altered the way educators and medical professionals are approaching human anatomy. They have changed classrooms and are beginning to allow for a greater understanding of and stronger approach to performing medical procedures. With the large number of computer programs, each with unique features and attractions, students are able choose which program accommodates their preferred learning style. Although reviews remain mixed on how 3D software should be used in an educational setting, students may have the opportunity to benefit from the vastly expanding technological world of anatomy programs. Using technology as a supplement to or replacement of cadaveric laboratories provides a cost-effective solution that enables remote instruction and addresses the needs of students who require a greater degree of flexibility in teaching modalities. However, most anatomy programs are used on a smaller scale and it is yet to be examined how a large-scale immersive classroom can influence students' learning and their ability to deeply understand structural relationships.

1.4. PHILOSOPHY OF EDUCATION

Philosophy forms the foundation of any educational system, including anatomy education. The term philosophy derives from the Greek words *phylosophia* meaning "love of wisdom" [143]. Philosophers seek to understand the fundamental truths about themselves, the world they live in, and its relationships to each other. It studies the nature of knowledge, reality, and existence and has had widespread effects on education. Educational research is primarily based on the influential works from Plato (428/427 BC to 348/347 BC), Immanuel Kant (1724 to 1804), John Dewey (1859 to 1952), Malcolm Knowles (1913 to 1997), Allan Bloom (1930 to 1992), David Kolb (born 1939), Howard Gardner (born 1943), and many others shaping our view on philosophy.

Plato, the first and most widely studied Athenian philosopher, was the student of Socrates and the teacher of Aristotle. His contribution to educational thought is mainly comprised of his theory described in *The Republic* (375 BC), which focuses on the need for understanding the student who is being taught and the teacher's role as master and a mentor for the student [144]. Plato proposed that the student would learn best while abiding the teacher and forming a loving relationship [145]. He claimed that education should be different for those who possess more ability and with that, he was one of the first philosophers who demanded equal education for men and women, as he saw them as equals in their ability to learn [145]. His views on equal education have influenced the educational system even today, as he believed that the curriculum needs to flexible in order to engage individual talents [146].

Immanuel Kant, a German philosopher in the 18th century, is known for his three critiques - *Critique of Pure Reason* (1781, 1787), *the Critique of Practical Reason* (1788), and the *Critique of Power and Judgement* (1790). In his work, Kant proposed fundamental searching questions focusing on how man can have knowledge, how man must act with the knowledge he has, and what man can hope for after doing what he is supposed to do [147]. His ethics focuses on the idea that all human beings are living under the same moral law called the "categorical imperative" [148]. His works address everyone who is trying to understand the world and human life as well as teachers seeking their rational of ideals. In education, Kant has proposed the importance of following universal rational duties and the learner's duty to respect humanity [149].

John Dewey was an American philosopher, educational reformer, and psychologist, and was seen as a leader of progressive education in the United States. He wrote influential books such as *Democracy and Education* (1916) and *Experience and Nature* (1925) proposing that a learner would learn best by doing a task. He believed that students need to be allowed to experience and interact with the environment and take an active role in their learning [150]. Contrary to many other educators in his time, he proposed that education should not focus on acquiring skills, but on promoting one's full potential. Dewey noted that "to prepare him for the future life means to give him command of himself; it means so to train him that he will have the full and ready use of all his capacities" [151]. His work has had major influence on the modern educational system, especially on critical thinking, as his teaching was composed of problem-solving exercises to identify, brainstorm, and apply a solution to a novel problem.

The word pedagogy is commonly used in education and is derived from the Greek meaning "a man having oversight of a child" [152]. In the modern day, the term is used for the study of knowledge and skills within an educational context, although some educators use it around child-centered education, whereas the term andragogy is referred to the education of adults. Malcolm Knowles was one such adult educator who famous for the theory of adult education. In his work *The Adult Learner: A Neglected Species* (1984), he emphasized four distinct principles in adult learning: (1) "Adults need to be involved in the planning and evaluation of their instruction", (2) "Experience (including mistakes) provides the basis for learning activities", (3) "Adults are most interested in learning subjects that have immediate relevance to their job or personal life", and (4) "Adult learning is problem-centered rather than content-oriented" [153]. This form of teaching and learning has been used extensively, shifting the traditional role of the teacher from lecturer (as stated by Plato) to facilitator, guide, and resource [154]. Knowles' theory of teaching adults in higher education has found its place in many instructional design courses and is reflected in the use of teaching methods such as case studies, role playing, and self-evaluation [154].

A commonly recognized model used to develop learning outcomes in the classroom is Allan Bloom's taxonomy. Allan Bloom, an American political philosopher, translated Rousseau and Plato's work during most of his career, but became popular after his publication of *The Closing of the American Mind* (1987). He argued that cultural relativism would negatively affect education and that universities were not teaching students how to think [156]. Bloom claimed that students needed Plato's *Republic* to examine ideas in a historical context. This created controversy, as his critique did not offer any solutions. His taxonomy, however, has been widely used in classrooms of all disciplines. It focuses on six hierarchical categories in the cognitive domain ranging from knowledge and comprehension to more advanced application, analysis, synthesis, and evaluation [157]. In 2001, a group of researchers revised Bloom's taxonomy to a more dynamic notion. Bloom's framework aids teachers in the formation of learning outcomes, planning and the delivery of instruction, and the design of assessments [158]. Additionally, it further promotes students to form a foundation of knowledge before acquiring critical thinking skills.

The term experiential learning was built upon the work of David Kolb, an educational theorist and psychologist, whose work was greatly influenced by the theories of John Dewey. His work in *Experiential Learning: Experience as the Source of Learning and Development* explains how the learner understands and processes new information [159]. His four-stage learning cycle is composed of (1) "concrete experience", (2) "reflective observation", (3) "abstract conceptualization", and (4) "active experimentation" [159]. In other words, the learner sees or experiences new information, thinks about it, forms new ideas, and applies the ideas to the surroundings. Kolb proposed that the most effective learning takes place when the learner goes through the entire cycle. Many educators have used his approach to experiential learning as it benefits both the learner and teacher, can be applied to modify curriculum development and outcome assessments [160], and promotes student understanding of their individual learning styles [161].

Howard Gardner is an American developmental psychologist who introduced the theory of multiple intelligences in education. He believed that conventional methods such as measuring the intelligent quotient of a learner would not recognize other cognitive abilities and that students would learn best if they were taught by methods that best addresses their learning style [162]. He also defined eight autonomous intelligences in his work, which can be found as a unique mix in each human being: "linguistic, logical-mathematical, spatial, musical, bodily-kinesthetic, interpersonal, intrapersonal, and naturalistic" [163]. The concept of differential thinking and learning processes among students has provided many educators in North America with a conceptual framework for their curricula and educational practices. To this date, many academic disciplines have adopted this idea and have applied it to all levels of education [163]. However, Gardner did not provide explicit applications on how to address each learner and thus the application of his theory varies. Psychologists and educators have critiqued Gardner's definition of multiple intelligences as it lacks empirical support [164] and is too broad representing only individual personalities and talents.

These researchers and many others have influenced current philosophers, psychologist, sociologists, and educationalists, and have ultimately shaped our understanding of knowledge, reality, and existence. The discipline of philosophy contributes fundamentally to any institution of higher learning, as it enables the learner to critically examine problems and enhance reading and writing skills. The philosophy of education further helps to understand the theory of education and formulates methods, which can then be applied and put into practice. Therefore, the social sciences can inform science disciplines through the use of these theories.

1.5. SUMMARY

Human anatomy is one of the foundational courses for students interested in learning about the human body or pursuing a career in a health-related field. It provides them with the opportunity to dissect a cadaver, be exposed to anatomical variations, acquire knowledge-based skills, and appreciate three-dimensional structural relationships. If students develop a good understanding of human anatomy, they are more likely to be successful as a health-care professional. Recent changes in the curriculum, however, have created unique challenges for anatomists to teach human anatomy. Time, faculty, and money devoted to the anatomical sciences have decreased and many schools have eliminated lectures and shifted to a more student-centered approach. Therefore, it is of importance that anatomists identify and implement methodologies that increase learning efficiency in the classroom, which will ultimately aid students in their success. As Bergman stated "there is no single method that can function as an answer for how anatomy should be taught. [....] it is not about the method you are using, but about how you are using it" [165].

Previous mixed methods studies have started to bridge the gap between research and practice in science teaching to incorporate more time efficient and active learning strategies. Within the cadaveric laboratory, anatomists have evaluated a dissection versus a prosection cadaver approach, evaluated the use of weekly assessments in the form of table conferences or checklists, compared independent and facilitated small group learning environments, and incorporated clinical correlations in order to teach human anatomy. Outside the cadaveric laboratory, institutions have implemented and analyzed the use of plastinated specimens, physical models, case scenarios, and computer-assisted learning programs to substitute donated cadavers in their anatomy classroom and enable remote instruction. These institutions have also shown that students gain a greater amount of knowledge, are more engaged, and acquire abundant skills if the teaching methods are purposefully incorporated into their anatomy curriculum. Most of these curricula are guided by the influential work of Plato, Immanuel Kant, John Dewey, Malcolm Knowles, Allan Bloom, David Kolb, and Howard Gardner, whose theories have been used in the social sciences for decades. Philosophy as the study of knowledge is the foundation of educational systems. Their work, combined with scientific research has led me to the following overarching research questions: How can we evaluate existing teaching methods in human anatomy curricula? How can we implement time efficient teaching methods in the human anatomy and neuroanatomy classroom? And how can these results inform future curricula and educators of other disciplines?

This body of work describes the evaluation of existing methods and the implementation of novel pedagogical techniques in the undergraduate and graduate human anatomy classrooms at Colorado State University in order to address the aforementioned research questions. The following studies focus on using low-stakes, frequent quizzing as an assessment tool in the gross anatomy laboratory, a description of a large-scale Virtual Reality deployment as a novel approach to distance education in human anatomy, a case analysis of group dynamics in two different cadaveric classrooms for instructional practices, and the utilization of case studies in neuroanatomy to improve critical thinking skills. Further, it describes the evaluation of a university-led summer anatomy camp that enables mentorship opportunities and uses critical thinking and hands-on anatomy exercises to promote STEM majors and careers. Using a mixed methods approach in these studies provides an in-depth view of how research participants experienced the implemented curricular changes in the classroom and expands our thinking of student outcomes. This work significantly contributes to the literature, as there is a need of educational research evaluating existing and novel teaching methods to become more time efficient in the human anatomy classroom. Further, it makes recommendations for anatomy educators and educators of other disciplines while taking student perceptions of integrated and multimodal teaching paradigms into account.

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CHAPTER II – TABLE QUIZZES AS AN ASSESSMENT TOOL IN THE GROSS ANATOMY LABORATORY[1][2][3]

2.1. SUMMARY

Using cadaveric instruction in a graduate-level anatomy course is an expensive and time-consuming undertaking. While this is a worthwhile endeavor, most first-year medical students and students in the health fields struggle with the independent, self-directed learning approach in the cadaveric laboratory, and going beyond rote memorization of the material. As such, effective assessment tools that maximize student learning in the cadaveric laboratory are critical, especially if no lecture component is present. Dissection quality often reflects student attention to detail and therefore may be tied to overall performance in the course. The aim of this study was to investigate the relationship between weekly table quizzes and the overall student outcomes in a graduate biomedical human dissection class as well as examining the benefits and implications of this approach. In this course, a uniquely structured weekly quiz assessed dissection quality and probed student understanding in human anatomy. Student data compiled from 5 years of dissection courses were analyzed to evaluate the relationship between performance in the weekly assessment and on the unit examinations. The results showed a statistically significant relationship between the weekly quizzes and the student examinations at the end of each dissection block in 2013, 2015, 2016, and 2017. The data suggest a potential correlation between performance on weekly quizzes and on unit examinations. The unique nature of the table quizzes provides the students with the opportunity to practice the retrieval of their knowledge, feel more guided throughout their dissection, and receive

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[1] This chapter is a slightly modified version of *Table Quizzes as an Assessment Tool in the Gross Anatomy Laboratory* published in *Medical Education and Curricular Development* and has been reproduced here with the permission of the copyright holder.
[2] Reference: Heise N, Meyer CA, Garbe BA, Hall HA, Clapp TR. 2020, Table quizzes as an assessment tool in the gross anatomy laboratory. *Medical Education and Curricular Development*. 2020; 7.
[3] Link: https://journals.sagepub.com/doi/10.1177/2382120520941822

immediate feedback on their performance. This assessment tool also provides a way to predict student outcomes and an opportunity for early intervention to help at-risk students. The analysis of this research study contributes to the need for more data on the usage of assessment tools in a graduate human dissection class.

2.2. INTRODUCTION

Every year, the number of medical students gradually increases within the United States [1] and often, first-year students find gross anatomy to be particularly challenging. Ongoing research on various educational techniques such as repeated and early intervention techniques that promote learning and retention in other disciplines has been well documented, but there are many unique challenges that are faced by medical programs or other institutions that offer gross anatomy laboratory classes. In addition, anatomical education has changed over the past decades. Since the 1990s, medical schools in the United States have revised their curricula toward a more student-centered instruction while reducing the time devoted to the anatomical sciences [2-6]. Many graduate programs offering cadaveric class- rooms have followed this student-centered approach when teaching human anatomy. This puts additional pressure to identify methodologies that increase learning efficiency. In the 2014 survey of 55 graduate and medical programs within the United States, all programs indicated that they use cadavers as a primary instruction method in their gross anatomy class [5]. In addition, all programs have changed to either a partially or fully integrated curriculum connecting subjects such as neuroanatomy, gross anatomy, microscopy, and embryology [5]. Only 31 programs (56%) in the United States assess other competencies like professionalism, communication skills, and teamwork building [5]. In addition, many schools have moved away from lecture-based methods and some even completely eliminated traditional anatomy lectures [7-10]. These changes have created challenges for anatomists to develop new strategies to teach human anatomy [5].

Within the medical field, educators have worked on implementing various assessment tools to not only improve student performance in anatomical courses but also to deepen their understanding and increase long-term retention of material [11]. Here, we describe the implementation of weekly table quizzes as an assessment tool. These oral quizzes between a facilitator and a group of 4 dissectors assess dissection quality while giving the opportunity to work with contextual information.

2.2.1. Retrieval Practice

Scientific and educational literature agrees that frequent, inter- active quizzing is related to improved student outcomes [12,13]. Regular assessments as an integral part in different learning environments engage students, enhance learning [14], encourage them to stay motivated and review more often, enable student- teacher interactions [11,15], and increase retrieval of knowledge. Karpicke [16] proposed that it is impossible to directly assess the contents of stored knowledge. One can only examine students' reconstructed knowledge [17-19]. In Karpicke study, 3 groups of students were given a scientific text and then exposed to different levels of rereading information or retrieving information. Results indicated that the group with the most active retrieval method produced the best long-term retention [16]. However, most students are unaware of using retrieval-based learning for enhancing their learning [20]. Several recent studies have shown that low-stakes quizzes that are interspersed in the course can serve as an effective tool for promoting retrieval practice [21-23]. Another study indicated that repeated recall in the classroom enhanced retention by more than 100% relative to not recalling them frequently [24]. These studies and other studies show that it is critical to practice retrieval for learning in the classroom [25]. Practicing the retrieval of knowledge through various exercises is a valuable skill for all students but does require time. However, with the decreased time devoted to the anatomical sciences, it remains questionable how feasible the implementation of this approach might be in a busy cadaveric classroom.

2.2.2. Feedback

Regular effective evaluation in the classroom is also critical in promoting student learning. When comparing multiple-choice vs short-answer formats, studies indicate that regular short- answer quizzes paired with targeted instructor comments that we often define as instructor feedback are more effective in enhancing student learning rather than taking a multiple- choice format [26,27]. Most cadaver-based anatomy classes refer back to the use of multiple different active learning strategies in implementing problem-based learning, life models, radiological images, and laparoscopic views of the living body. Armbruster and colleagues implemented active learning and student-centered pedagogy in an introductory biology class with the hope to improve student attitudes and performance [28]. Results indicated that students performed better on final examinations when material was taught in an interactive form. Interactivity included emphasizing learning goals during lectures with clicker questions, weekly quizzes, group work, recitation, and outside class study groups. The weekly quizzes were considered a helpful lecture element and ranked third highest in helpfulness. These weekly quizzes were implemented to encourage students to keep up with the material and to provide feedback [28]. In addition, other literature has shown that weekly quizzes can help students to form links and relationships between clinical facts and other concepts [29-33]. However, in a shortened time devoted to the anatomical sciences and with a decrease in faculty and staff present in the laboratory, anatomy facilitators have faced problems incorporating this approach in providing frequent feedback.

2.2.3. Assessment-Driven Learning

Most cadaveric classrooms have shifted to an independent, self-directed learning environment in which students are required to link concepts on their own. This is particularly challenging if no lecture component is present. Weekly oral quizzes, as well as checklists, may provide discussion assessment-driven learning in the cadaveric classroom. Checklists have been used to evaluate learning in a gross anatomy laboratory to improve dissection quality and to assist students in improving learning outcomes and maintaining focus [34]. Halliday et al. implemented regular assessments into their medical school anatomy curricula to incentivize students to keep up with the material and provide students with regular checkpoints to assess their progress [35]. In another study, students reported that they saw weekly assessment of their dissection as a "valuable and rewarding part of their anatomy course" and 64% of students agreed that the evaluation of their dissection in form of weekly quizzes helped them to use their laboratory time efficiently [36]. Nevertheless, more data are needed on this approach on how to effectively guide students in a more condensed cadaveric classroom environment.

2.2.4. Targeted Intervention

Predicting student outcomes and ultimately determining at- risk students has gained of great interest to provide sufficient help for students in need and ultimately increase student out- comes. Literature has looked into ways on how to identify students who are going to do poorly in a course early enough so remedial actions can take place [37]. An example of such is reported by Meier and colleagues [37] who created an algorithm that focuses on the past history of students' performance in a course and proposed that early in-class assessments such as quizzes would enable timely interventions by the instructor. Others have used personalized multi-regression and matrix factorization approaches [38] or the analytics of using a digital textbook [39] to forecast student outcomes. The literature asks for more research on how to effectively intervene and help students in need in a timely manner.

2.2.5. Summary

Although many studies have demonstrated the success of various supplemental materials in the cadaveric laboratory, it is important to continue to evaluate pedagogical methods and determine their benefits and implications. Student tendencies to focus on gaining rote knowledge and memorizing the material should be supplemented with active learning strategies to let them practice the retrieval of their knowledge and receive immediate feedback on their progress. Students enrolled in a dissection course without a lecture component, as described in this study, may be in particular need of active learning to guide and encourage their independent study. The aim of this study was to investigate the relationship between uniquely structured weekly table quizzes and the overall student outcomes in a graduate biomedical human dissection class as well as examine the benefits for faculty and staff of this approach in predicting student outcomes. The data from weekly table quizzes described in this study may further support the literature in examining the advantages of frequent assessment, feedback, and guidance in a cadaveric laboratory.

2.3. MATERIALS AND METHODS

2.3.1. Ethical Approval

This study was reviewed by the Institutional Review Board at Colorado State University and did not require approval because it did not involve intervention or interaction with the individual or identifiable private information (45CFR46.1029(f)).

2.3.2. Student Cohort

For this study, the sample is composed of students who were enrolled in the graduate human gross anatomy dissection class at Colorado State University (Table 2.1). Thus, all registered students were part of this study and therefore formed an opportunity sample. In the fall 2013, 46 students were admitted to the class. In the fall 2012, 2015, and 2016, 48 students each were enrolled in the class and in 2017, 55 students. The age range of the participants was between 20 and 35 years. Undergraduate students with a major in biomedical sciences, biology, or health and exercise sciences made up one third of the class. The other two thirds of the class were graduate students enrolled in the 1-year master's program in biomedical sciences. Each semester, approximately 1 to 2 graduate students from a toxicology master's program were enrolled as well. Every semester, the class was composed of approximately half female and half male students. Transcripts were reviewed before enrollment, and these showed that all students began the class with a diverse background in human anatomy. Approximately half of the students were previously enrolled in an undergraduate prosection gross anatomy course. The remainder of the student cohort had no sufficient anatomy knowledge and were recommended to take an undergraduate prosection gross anatomy class prior to enrollment or concurrently. The cadaveric prosection course provided a lecture component that is beneficial to students without an anatomy background.

Table 2.1 Population Characteristics

YEARS	2012	2013	2015	2016	2017
# of students	48	46	48	48	55
Age range	20-35 years				
Enrollment	1/3rd undergraduate and 2/3rd graduate students				

Population characteristics from the years of 2012, 2013, 2015, 2016, and 2017 with number (#) of students, age range, and enrollment.

2.3.3. Course Structure and Grading

Students enrolled in graduate human gross anatomy dissection worked in groups of 4 to dissect a human cadaver over the course of a 16-week semester. The individual groups were formed based on students' self-selection. Each group was assigned to a specific cadaver on the first day of classes and was required to follow regional dissection blocks to finish the dissection by the end of the semester. Each dissection block was 4 weeks long and incorporated 3 weekly quizzes, termed table quizzes, and 1 laboratory examination that tested student knowledge. However, the first dissection block was only composed of 2 table quizzes due to timing between the start of the semester and the first examination. The 4 examinations comprised 80% of the students' final grade and table quizzes comprised the remaining 20%. At the end of the semester, students were allowed to drop 1 (lowest) weekly table quiz grade. The course comprised solely laboratory instruction time, with no lecture component. The course was scheduled 3 times a week for 3 hours in the afternoon. During this time, students dissected with the presence of 2 professors, 1 instructor, and up to 5 teaching assistants. In addition, the students were required to work on their cadavers outside of class to finish the dissection that was required for each week. Because there was no lecture component for this course, the students were required to work with Grant's Dissector [40] and the Atlas of Human Anatomy [41]. Weekly dissection guides of 2 to 3 pages supplemented the available resources, outlining highlights of the related week. Similar details on the course design and dissection have been described by Nwachukwu and colleagues [36]. As stated, students who did not have sufficient anatomy knowledge were also required to enroll in the undergraduate prosection class which was composed of 3 1-hour lectures on Mondays, Wednesdays, and Fridays, as well as a prosection-based laboratory component once a week for 3 hours.

2.3.4. Cadaveric Dissection

Embalmed cadavers were received from the State Anatomical Board, an agency based out of the University of Colorado at Denver and the Health Sciences Center. Each year, 12 to 14 cadavers were used for the dissection course. Around 10 dissected cadavers from the previous year were used for the pro-section gross anatomy course on campus and also served as an important tool to guide the students in their dissection. The dissection class was organized into 4 blocks with a focus on the lower limb, thorax/abdomen/pelvis, head/neck, and upper limb. Because the anatomical areas varied in size, difficulty, and detail, it was required that the students equally contribute to the dissections outside of class among their group.

2.3.5. Laboratory Examinations and Weekly Table Quizzes

To assess student knowledge in human anatomy, faculty, staff, and graduate teaching assistants tagged anatomical structures on the cadavers students were working on for the laboratory examinations. A total of 80% to 90% of the tagged structures required identification, whereas 10% to 20% focused on application of knowledge. Preference in choosing examination questions was given to structures from the Grant's Dissector [40] or Atlas of Human Anatomy [41] and those that have clinical relevance. These examinations were facilitated in an individual and written format. In addition to the laboratory examinations, table quizzes were implemented to primarily assess dissection quality. The goal for these weekly table quizzes was to monitor dissection quality and to ensure that students were able to identify anatomical structures as well as add contextual information (e.g., relevant innervation and blood supply). While this exercise enhanced communication within the small group of dissectors, it also provided the instructors with the opportunity to informally assess individual and group understanding. These table quizzes were composed of 10 structures relevant to the current unit and took place on Monday of each week, testing the material from the previous week. Each question in these assessments was equally worth 10% of the maximum 5 points for the quiz. On alternating weeks, the table quizzes included an extra credit question which was worth 0.5 points. The example table quiz in Table 2.2 illustrates a typical set of structures within the thigh and gluteal region of the lower limb dissection unit. Every week, in preparation for the table quiz, faculty and staff would meet and discuss relevant structures to determine the components of each table quiz. The instructors chose a combination of muscles, arteries, nerves, ligaments, or other important structures in that region that was also described in the Grant's Dissector [40] or Atlas of Human Anatomy [41]. Additional questions as well as requirements for receiving credit for each structure were discussed and noted during those meetings. The notes taken during those meetings formed a base for conversations between faculty and students during the weekly table quizzes and outlined information in each rubric (example illustrated in Table 2.3). These meetings were crucial to ensure objectivity of assessments. Frequently, graduate teaching assistants paired with faculty and staff to assist with this assessment. This assessment tool required the students to clearly identify anatomical structures, trace them, and know important characteristics about the structures, such as origin and insertion of a muscle or terminal branches of a vessel or nerve. However, during early implementation in 2012, the table quizzes solely focused on identification and dissection quality of the observed structures. In an effort to constantly improve pedagogical technique, second- and third-order questions were added in 2013 to increase the depth of knowledge tested with this assessment tool.

The process of the weekly oral table quizzes began with the evaluator giving students a structure to identify and giving them 1minute of small group discussion. No learning cues were given throughout this time. The students used that time to share their knowledge with each other and find the anatomical structure on their cadaver. Providing the group time to work collaboratively was important to give each person an equal opportunity to contribute detailed knowledge. Following this discussion time, the evaluator checked the identified structure. In addition, the group had to answer verbal questions from the evaluator which was not a structured part of this assessment. The grading criteria focused on an assessment of the quality of the dissection. If the entirety of the structure was clearly distinguishable from surrounding structures and fascia was appropriately removed, the group received the points (Table 2.3). Even though the quality of the dissection determined the grade received for the table quiz, the evaluator also posed critical thinking questions to interact with the students and create a learning environment. For example, the following questions would be asked for the first structure (transverse branch of lateral circumflex femoral artery) as seen in Table 2.2:

- *What area does this artery supply blood to?*
- *Where does this artery branch off from?*
- *What are other named branches of the same artery? Are there any existing anastomoses?*

This verbal interaction was implemented to test student knowledge besides the dissection quality as no lecture component provided additional learning opportunities and students were required to independently draw connections between structures. Because students' knowledge varied throughout the cohort, the additional questions asked differed between each dissection group. A discussion of structural relationships and oral questions resulted in a student-teacher interaction and feedback of approximately 20 to 25 minutes during each table quiz. Feedback was provided immediately after each structure ensuring immediate understanding of the material. In addition, each individual student was given the opportunity to communicate with the instructor and work through follow-up questions. Instructors ensured everyone within the small group participated and contributed to the group grade. This approach allowed the assessment of collaborative as well as individual effort. To make this process more efficient, faculty and staff alternated between groups to interact with 1 group while another group was working independently to discuss the anatomical structure. This allowed each group time to work independently and to work with the instructor on critical thinking questions, making this process more feasible in a busy cadaver laboratory. Group performances were recorded of a total of 5 points in form of grades in an online learning management system (Canvas).

Table 2.2 Example Table Quiz Within Lower Limb Dissection Block

STRUCTURES 1-5	STRUCTURES 6-10
1. Transverse branch of lateral circumflex femoral artery (0.5 points) 2. Superior lateral geniculate artery (0.5 points) 3. Long head of biceps femoris muscle (0.5 points) 4. Obturator nerve (0.5 points) 5. Lateral femoral cutaneous nerve (0.5 points)	6. Sciatic nerve (0.5 points) 7. Vastus medialis muscle (0.5 points) 8. Gluteus medius muscle (0.5 points) 9. Superior gluteal nerve (0.5 points) 10. Obturator internus muscle (0.5 points) Extra credit: pes anserine (0.5 points)

List of example anatomical structures chosen for a table quiz within the lower limb dissection block. All 10 questions were worth each 0.5 points with a total of 5 points. On alternating weeks, an extra credit structure was given which increased the total to 5.5 points.

Table 2.3 Table Quiz Rubric

MUSCLE REQUIREMENT	ARTERY/VEIN REQUIREMENT	NERVE REQUIREMENT	LIGAMENT REQUIREMENT
intact throughout region	intact throughout region	intact throughout region	intact throughout region
Free from fascia/surrounding tissues	Free from fascia/surrounding tissues	Free from fascia/surrounding tissues	Free from fascia/surrounding tissues
Origin and insertion visible	Traceable through entire region	Traceable through entire region	Attachment points visible
Muscle striations and borders visible	Muscular branches visible	if applicable: muscular branches visible	
if applicable: complete reflection according to weekly dissection guide	if a branch: root and other branches visible		

Rubric was used during table quizzes for grading purposes. Muscles, arteries and veins, nerves, and ligaments had requirements that needed to be checked during the table quizzes. Full points were given when all requirements were completed. No partial credit was given.

2.3.6. Data Analysis

After the grades were collected through the online learning management system (Canvas), the table quiz grades were com- pared with the laboratory examination scores. For each student, table quiz grades within 1 dissection block were averaged. The averaged table quiz grades were correlated to the relevant laboratory examination score for each individual student. Linear regression was performed in Microsoft Excel (Microsoft, Redmond, WA). In this study, it was used to make a prediction and examine the relationship between table quizzes and examinations. Linear regression was performed in live time after each examination. This analysis allowed the facilitators to predict student outcomes and intervene within their progress to increase student success in the class. All grades were considered in this study, and statistical significance was set at the 0.01 level. Because the residuals were approximately normally distributed, Pearson parametric correlation was used to analyze the data. The regression coefficients R^2 and P values for the years 2012, 2013, 2015, 2016, and 2017 were recorded. The data from the fall 2014 were corrupted and thus were not part of this study. The regression analyses allowed for longitudinal comparison of the effectiveness of table quizzes at improving student learning and dissection quality across multiple years.

2.4. RESULTS

Quantitative analysis of student grades revealed a statistically significant positive relationship between the averaged table quiz grades and the student examination scores in 2013, 2015, 2016, and 2017 (Table 2.4). The number of data points (observations) varied in each year due to the change in enrollment. Linear regression provides a visual appreciation of the association between improvement in table quiz grades and increased examination scores (Figures 2.1-2.5).

In 2013, linear regression of the data showed a regression coefficient R^2 of 0.1191, $P < .001$. In that year, 46 students were enrolled which resulted in a recording of 184 grades across all 4 dissection units. The data points from the averaged table quizzes ranged from 2.25 to 5.17 points (45%-103.4%) and the examination scores ranged from 22 to 51 points (44%-102%). Linear regression of 2015 data showed an R^2 of 0.0395, $P < .0057$, with an enrollment of 48 students that year and a collection of 192 grades. Range of averaged table quiz scores was 3.5 to 5.4 points (70%-108%) and 28 to 51 points (56%-102%) for examination scores. 2016 data showed an R^2 of 0.2137, $P < .001$. The enrollment of students was 48 with a collection of 192 grades. The averaged table quiz scores ranged from 2 to 5.34 points (40%-108%), and the examination scores were in between 33 and 51 points (66%-102%). Finally, the 2017 data had an R^2 of 0.21304, $P < .001$, with 55 students enrolled that year and a collection of 220 grades. The range of averaged table quiz scores was 2 to 5.5 points (40%-110%), and the range of examination scores was 27 to 51 points (54%-102%).

Data analyzed from grades collected in 2012 showed no significant relationship. R^2 from 2012 was 0.0001, $P = .8774$. In that year, 48 students were enrolled, and 192 grades were collected. The averaged table quiz scores ranged from 2.25 to 5.17 points (45%-103.4%) and the examination scores ranged from 17 to 50 points (34%-100%).

As mentioned previously, the range of averaged table quiz scores varied throughout the years. The data from 2012 and 2013 showed that the range of averaged table quiz scores is the same for those 2 years (58.4%). Surprisingly, the range in 2015 decreased (38%) and increased again in 2016 (68%) with 2017 representing the biggest range (70%). In 2015, students performed better on table quizzes which resulted in this narrow range of data points. The range of examination scores decreased over the years from 2012 (66%) to 2016 (36%). In 2017, however, the range was again the biggest (66%).

An analysis of the means of all table quizzes combined and all examination scores for each year revealed lower means for examination scores than table quizzes for 2012 and 2015 (Figure 2.6) indicating that students performed better on table quizzes when compared with examination scores. The reversed relationship was observed in 2013, 2016, and 2017 showing that students performed better on examinations than on table quizzes. The highest mean was found in 2015 (92.483%) for the table quizzes and the lowest in 2013 for table quizzes (78.140%).

Table 2.4 Results from Regression Analysis from 2012, 2013, 2015, 2016, and 2017

Years	2012	2013*	2015*	2016*	2017*
P-Values	0.8774	< 0.001	0.0057	< 0.0001	< 0.0001
R Squares	0.0008	0.1191	0.0395	0.2137	0.2130
Observations	192	184	192	192	220
Range TQ	45-103.4	45-103.4	70-108	40-108	40-110
Range E	34-100	44-102	56-102	66-102	54-102

Summary of regression analysis is shown in Figures 2.1 to 2.5. P values determined the significance of the comparison of averaged weekly table quizzes and examination scores in 2012, 2013, 2015, 2016, and 2017. Statistically significant years with $P < .01$ were indicated with *. R^2 values indicated how close the data were to the fitted regression line. The observations included 4 averaged table quizzes, each compared with the respective unit examination scores for each student in that year. in 2012, 2015, and 2016, 48 students were enrolled. in 2013, 46 students and in 2017, 55 students. The range of the averaged table quiz scores (TQ) and examination scores (E) varied throughout the years and is indicated in percent from lowest to highest (%).

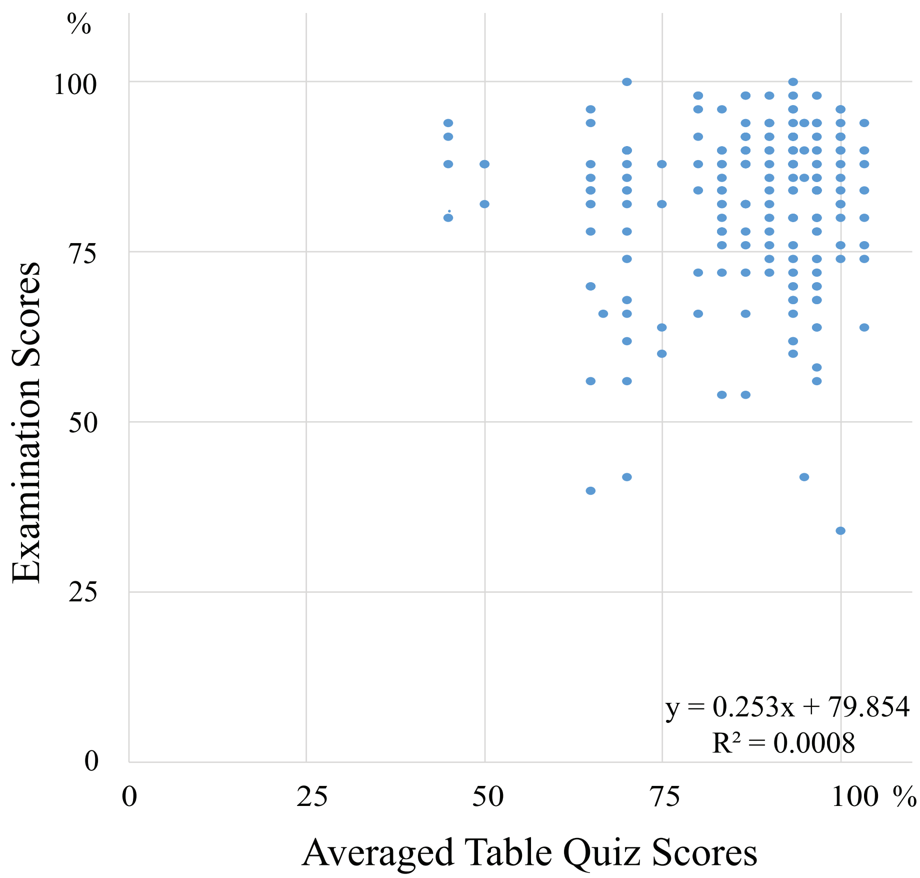

Figure 2.1 Linear Regression Analysis 2012

Regression analysis comparing averaged table quiz scores and examination scores in each dissection unit in 2012. The maximum score (100%) of each table quiz was 5 and 5.5 with the extra credit question. The maximum score (100%) of each examination was 50 points and 51 points including the extra credit question. Each student is represented 4 times in this figure due to the 4 dissection blocks. in this year, 48 students were enrolled in the class resulting in 192 grades.

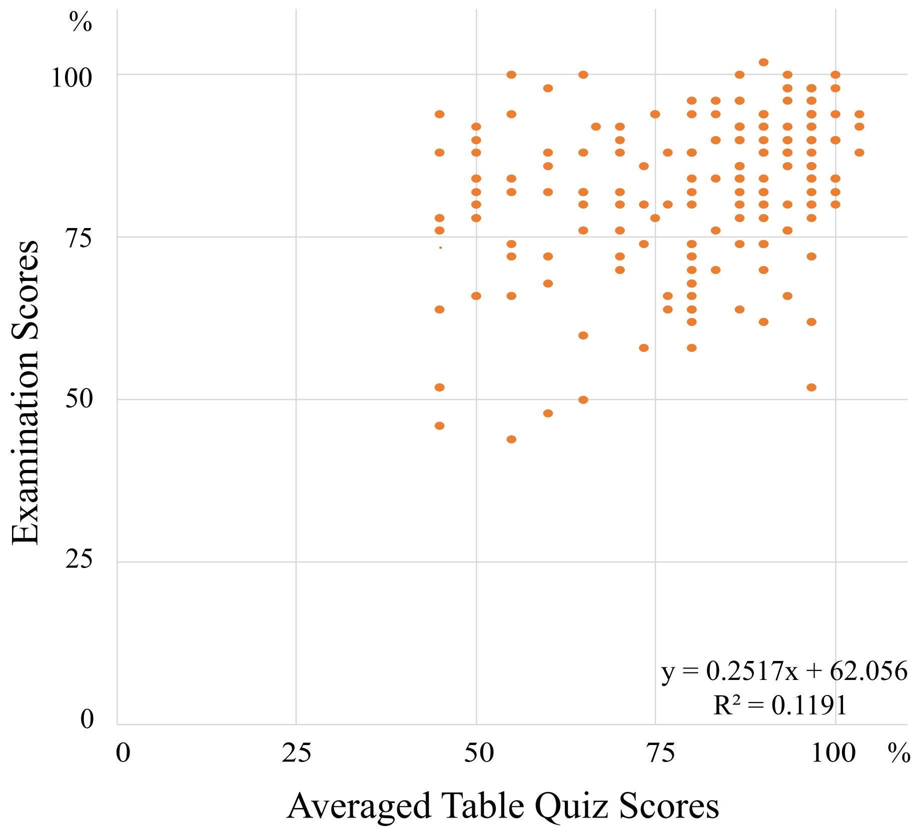

Figure 2.2 Linear Regression Analysis 2013

Regression analysis comparing averaged table quiz scores and examination scores in each dissection unit in 2013. The maximum score (100%) of each table quiz was 5 and 5.5 with the extra credit question. The maximum score (100%) of each examination was 50 points and 51 points including the extra credit question. Each student is represented 4 times in this figure due to the 4 dissection blocks. in this year, 46 students were enrolled in the class resulting in 184 grades.

Figure 2.3 Linear Regression Analysis 2015

Regression analysis comparing averaged table quiz scores and final examination scores in each dissection unit in 2015. The maximum score (100%) of each table quiz was 5 and 5.5 with the extra credit question. The maximum score (100%) of each examination was 50 points and 51 points including the extra credit question. Each student is represented 4 times in this figure due to the 4 dissection blocks. in this year, 48 students were enrolled in the class resulting in 192 grades.

Figure 2.4 Linear Regression Analysis 2016

Regression analysis comparing averaged table quiz scores and final examination scores in each dissection unit in 2016. The maximum score (100%) of each table quiz was 5 and 5.5 with the extra credit question. The maximum score (100%) of each examination was 50 points and 51 points including the extra credit question. Each student is represented 4 times in this figure due to the 4 dissection blocks. in this year, 48 students were enrolled in the class resulting in 192 grades.

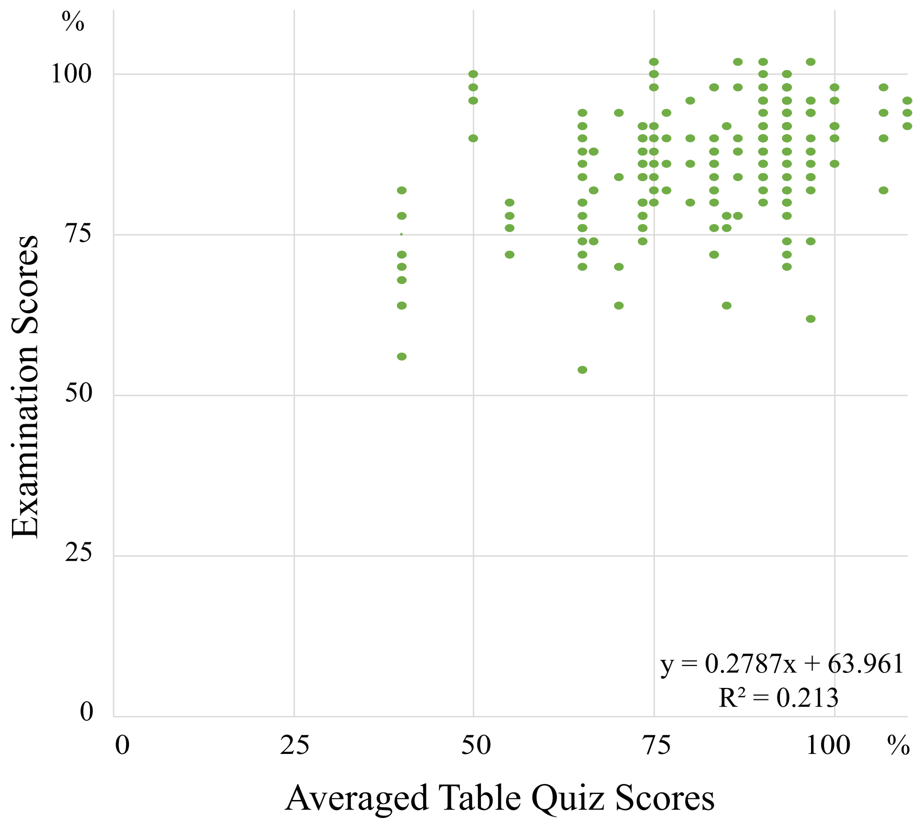

Figure 2.5 Linear Regression Analysis 2017

Regression analysis comparing averaged table quiz scores and final examination scores in each dissection unit in 2017. The maximum score (100%) of each table quiz was 5 and 5.5 with the extra credit question. The maximum score (100%) of each examination was 50 points and 51 points including the extra credit question. Each student is represented 4 times in this figure due to the 4 dissection blocks. in this year, 55 students were enrolled in the class resulting in 220 grades.

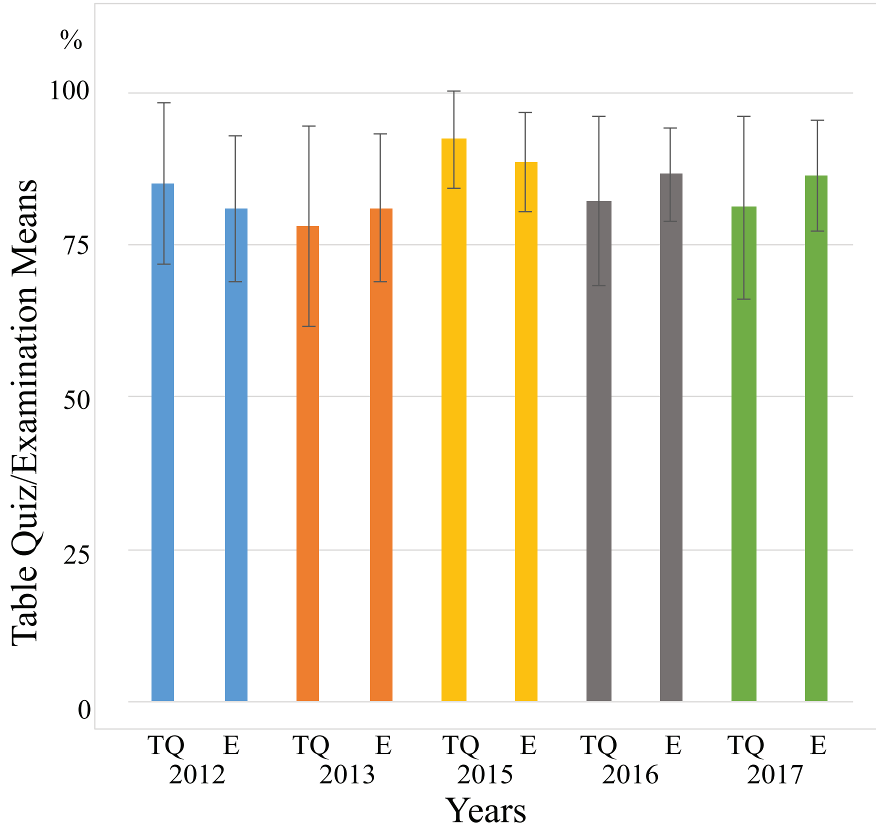

Figure 2.6 Table Quiz and Examination Score Means from 2012, 2013, 2015, 2016, and 2017

Statistical analysis comparing means of all table quizzes and examination scores for each year ± standard deviation. The first bar of each color represents the mean for table quizzes (Tq), whereas the second bar illustrated the mean of all examination scores (E).

2.5. DISCUSSION

In this study, the results indicate that there is a positive relationship between the table quizzes and the laboratory examination scores in the graduate-level human dissection course in the years of 2013, 2015, 2016, and 2017. Surprisingly, 2012 did not indicate a significant correlation between the 2. Throughout the table quizzes in 2012, faculty and staff solely focused on identification and dissection quality of the observed structures using no specific grading rubric. The table quizzes took around 10 minutes and did not include an oral component because the students simply had to point to the anatomical structures. Beginning with 2013, faculty and staff added application questions to create a dialogue and feedback between students and faculty. This adjustment and creation of a more active learning environment may have resulted in the observed positive relationship in future years which is supported by the literature [12,13,28-34]. Because the instructors have changed minimally over the years, the stronger correlations in later years may be explained by the instructors improving their skills regarding the table quizzes and their communication with the students. One critical component of this improvement was changing the table quizzes to a more conversation-based assessment and increasing the duration to 20 to 25 minutes with each group. Other studies also support the benefits of immediate feedback and have shown that this can result in a higher performance and affect retrieval of information [26-33]. Active learning is more engaging than memorization which might aid in understanding the presented anatomical material on a deeper level [42,43].

In our course, we let students self-select their groups which may have had an impact on how thoroughly they dissect. This also may have influenced the overall mean table quiz and examination scores for each of the years as seen in Figure 2.6. Literature suggests that students generally perform better on group examinations than during individual testing circumstances [44-46]. This is supported by our data from 2012 and 2015. In addition, it is possible that high stakes and high point totals of individual examinations could have affected the different total mean scores.

Strategies to increase active learning in a gross anatomy laboratory and other scientific classes, such as frequent quizzes, have previously been shown to be successful [12,13,28-34,47]. One particular study focused on a cadaveric classroom and showed a similar positive correlation between the dissection assessment and the final course grades [36]. However, this previous study focuses mainly on dissection quality and not on higher order thinking and anatomical knowledge gained through the weekly quizzes or on how to use this information for targeted intervention. The current study supports these findings while further developing the benefits of this assessment tool. The visual representation of the data (Figures 2.1-2.5) aids in tracking student progress and predicting student outcomes throughout the semester which has previously been shown to help identify at- risk students [37-39]. Performing regression analysis after the first examination was especially helpful as faculty and staff were able to evaluate the students' progress and provide early help if necessary. Teaching assistants were assigned to give additional instruction to groups who performed poorly on weekly table quizzes. The weekly examination of dissection quality and assessing student knowledge may be a way of using the given laboratory time effectively in getting to know the students and intervene during their learning progress if necessary [37-39]. In addition, the weekly quizzes enabled the students to practice retrieval and recall anatomical structures and content within the classroom as supported by the literature [21-25]. These table quizzes also encouraged students to keep up with the material and stay motivated throughout the semester. While not formally assessed, the oral component served as feedback that played a critical role in enhancing student learning as supported by previous studies [26,27,48,49]. Oral examinations can serve as a reliable and objective means to monitor students' progress in a cadaveric anatomy course [50]. According to Johnson and colleagues, the supplementation of oral quizzes improved student learning in a laboratory dissection class [51]. These examinations during the dis- section served as "spot checks" on anatomical areas which were followed by faculty advice on how to improve and maintain focus [51]. This and other studies reported that the implementation of those assessments keep students motivated and guide them throughout their dissection [52].

Students in this study were required to learn a lot of information in a short amount of time with no lecture component associated with this course, and it was critical that faculty create an active learning environment to engage students. Frequently, students in a self-directed learning situation feel overwhelmed and are less likely to find learning strategies on their own [53]. The course described in this study is primarily self-directed instruction and the weekly table quizzes are an important activity to engage students in active learning. This form of assessment is similar to the previously described spaced practice during which the content of 1 dissection unit is spaced out over time and tested throughout the unit instead of only at the end [54,55]. In addition to the retention of knowledge gained through weekly table quizzes, the dissection process may have enhanced student technical skills as described previously [36].

2.5.1. Limitations and Future Research

To determine whether the table quizzes have an impact on the students' learning and knowledge retention, it would be beneficial to formally assess the oral component of this assessment tool. This study only demonstrated an increase in examination scores based on dissection quality. Analyzing the higher order thinking questions posed during the student instructor inter- actions might contribute in determining whether students retained the material and whether it increased their knowledge in human anatomy. Another potential limitation of this study is the lack of a control group. It would be beneficial to compare a group of students exposed to table quizzes and examinations with a group of students only taking examinations. However, eliminating table quizzes for a group of students would prevent faculty from using this quiz as an early gauge of student progress. In this course, the instructors used the table quizzes not only to prepare the students for their upcoming examination but also to interact with the students and recognize weaknesses. Before the table quizzes were implemented, instructors would solely focus on the first examination grade to recognize and reach out to academically at- risk students. While not a formal purpose of this assessment, it has proved invaluable in allowing faculty to intervene for students who are struggling with the material prior to receiving a failing grade on the first examination. As such, it would be difficult in the current course setup to create a control group without sacrificing student performance.

Another limitation of this study is that statistical analysis revealed a regression coefficient of no more than 21%, indicating that this model needs improvement. Comparing averaged table quiz and final examination scores shows a potentially beneficial correlation but does not directly imply a causal link between improved table quiz scores and examination scores. It is difficult to capture the complexities leading to student examination success. Motivation, time spent dissecting, and understanding of dissection guides were not directly measured in this study. For example, a student who may have done poorly during table quizzes may make up for their individual final examination grades through increased study efforts. In addition, it is important to keep the grading throughout the table quizzes as objective as possible. The subjectivity of faculty and staff was controlled through a set rubric but ultimately may have influenced group table quiz scores.

The research team hopes to continue the implementation of this assessment tool in the dissection classroom, to adjust specific delivery methods, to analyze the results, and to ultimately improve human anatomy instruction. To better assess this method, it is essential to gather qualitative data on how the students perceive the table quizzes throughout the semester. This type of data could strengthen the usage of table quizzes in the gross anatomy laboratory. In addition, focusing on the oral component of the table quizzes could reveal more aspects beneficial for teaching in the cadaveric laboratory as well as an opportunity to formally assess student knowledge. In the future, student success and feedback will continue to drive innovation in identifying distinct learning methods for optimal knowledge acquisition.

2.6. CONCLUSION

Educational research in anatomical sciences indicates that assessment tools not only enhance a positive laboratory experience but also provide students with direction and guidance while working with their cadavers during their laboratory time [51,56]. While current literature supports the use of assessment tools, further studies are needed to demonstrate the effectiveness of these educational tools in cadaveric laboratories. Thus, this longitudinal study of implementing oral table quizzes over 5 years helps to support the usage of assessment tools in all cadaveric laboratories that evaluate dissection quality. The unique nature of the table quizzes provided the students with the opportunity to practice the retrieval of their knowledge and feel more guided throughout their dissection. In addition, they were able to interact with faculty and staff and receive immediate feedback on performance throughout the course. This approach creates the opportunity for facilitators to assess dissection quality while giving them the opportunity to introduce higher order questions.

This approach may be useful for instructors teaching human anatomy in a stand-alone laboratory setting without a lecture component and for instructors seeking ways to work more closely with their students. In addition, this assessment tool might contribute in filling the gap of incorporating active learning strategies in a busy cadaveric laboratory.

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CHAPTER III – A LARGE-SCALE VIRTUAL REALITY DEPLOYMENT: A NOVEL APPROACH TO DISTANCE EDUCATION IN HUMAN ANATOMY[4][5]

3.1. SUMMARY

The arrival of COVID-19 restrictions posed challenges to education communities worldwide. In response to these changes, Colorado State University coordinated and deployed a large-scale virtual reality (VR) course to supplement online human anatomy instruction. Students received a VR capable laptop and head-mounted display and participated in 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 was collected on student engagement, confidence, and reactions to the new technology. Quantitative data assessed student knowledge acquisition and retention of anatomical spatial relationships. Results indicated a statistically significant increase in examination scores in the online course when compared to previous in-person laboratories. Utilization of VR promoted student engagement and increased opportunities for students to interact with teaching assistants, peers, and course content. Notably, students reported VR associated benefits that focused on unique aspects of their virtual learning environment such as the ability infinitely scale the cadaver and walk inside and around anatomical structures. Student feedback suggested that students had the opportunity to explore anatomical content from novel perspectives that added to their overall learning experience. Mixed results suggested that using VR was equivalent to 2D methods in student knowledge acquisition and retention of anatomical 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

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[4] This chapter is a slightly modified version of *A Large-Scale Virtual Reality Deployment: A Novel Approach to Distance Education in Human Anatomy* currently under review in *Anatomical Sciences Education*.
[5] List of authors: Heise N*, Brown K*, Eitel CM, Nelson J, Garbe BA, Meyer CA, Ivie KR, Clapp TR (* indicates equal contribution)

compromising learner engagement. This course demonstrates an interactive approach to distance education and may further promote educational research utilization of VR to supplement teaching human anatomy.

3.2. INTRODUCTION

As a result of the COVID-19 pandemic, a rapid and massive global shift to remote coursework became necessary at all levels of education. This shift was challenging for gross anatomy laboratories, who traditionally rely heavily on in-person group work and hands-on activities. The repercussions of the pandemic have been well documented by anatomists and students [1-9]. A detailed thematic analysis of multiple institutions revealed loss of integrated "hands-on" experiences, changes in workload, and challenging anatomists' personal educational philosophies [7]. 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.

3.2.1. Online Laboratories

It is well established that laboratory experience is fundamental to a comprehensive and well-rounded STEM education [10-11]. It is therefore essential to create viable remote laboratory options to meet the growing need to accommodate increasingly diverse populations and locations of learners. Various remote instruction options have been continuously developed and utilized over the last 20 years [12] 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 [13-16]. Students have stated that distance education enabled them to continue their education by overcoming many obstacles [17]. In fall of 2018, around 6.9 million students were enrolled in distance education courses at degree-granting postsecondary institutions, which is an increase of 300,000 students compared to fall 2017 [18]. It is therefore of no surprise that online STEM laboratories have become an increasingly popular area of research as instructors work to increase accessibility of their coursework.

Carefully designed full-scale online laboratories can be an effective alternative to in-person laboratories, especially in understanding conceptual background knowledge [19-23]. Students have demonstrated equivalent knowledge acquisition and attitudes between in-person and online laboratory modules in physical science, chemistry, and biology [20,24-25]. Hands-on laboratory activities can be difficult to replicate in an online environment, previously demonstrated by online chemistry and physical science courses [11, 26].

Comparatively few studies have been published 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 [27-38]. Although the utilization of online resources as a supplement to in-person human gross anatomy laboratories is well studied [39-44], fully online anatomy laboratories remain a relatively un-studied niche. However, human anatomy coursework is no exception to the growing need of increased accessibility via remote learning as a few fully online anatomy laboratories have been developed to accommodate growing enrollment [45] and rural learners with long commute times [46], among other reasons. Attardi and Rogers 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 [45]. 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 [45]. This course was later modified to improve student engagement by increasing virtual interaction opportunities with instructors and peers using breakout virtual laboratory groups [47]. These virtual breakout laboratory groups improved engagement but were not comparable to the F2F laboratories [47]. 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 [46]. 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.

3.2.2. 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. The "versatile functionality and lightweight form" [48] 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 [49]. Using head tracking information to calculate viewing angles and allowing users to simply move their heads to get another perspective was likely the original three-dimensional (3D) interaction technique. In the last fifteen years, we have seen improvements in tracking and display, including reduced latency and increased accuracy in location and position tracking. These improvements 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 [50-53].

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 [53-55]. Students studying neuroanatomy using VR have reported higher satisfaction [55], motivation, engagement, immersion, and perceived usefulness [53-54] when compared to control groups using paper-based study methods.

Additionally, students have demonstrated equivalent [53] or greater knowledge retention in anatomical content [54] compared to paper-based control groups. These findings are corroborated by studies in other subjects, most notably chemistry and physics [56-57]. In a hands-on physics laboratory, students demonstrated greater conceptual knowledge gains using augmented reality (AR) compared to traditional laboratory setups [56]. In organic chemistry, students demonstrated equal learning outcomes between VR and traditional laboratory settings, and VR students reported a high level of engagement. The study suggested utilization of VR as a method to improve accessibility to students with disabilities, students who are unable to regularly attend an in-person laboratory, and students with safety concerns [57].

Learning human anatomy is a highly spatial activity and involves a thorough understanding of structural relationships [58]. 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 [58-60]. Therefore, it is important to investigate novel methods of improving student spatial abilities, in hopes of improving student understanding of anatomical spatial relationships. 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 [54-55]. However, more research is needed in this area to better quantify the relationship between utilization of VR and spatial ability/understanding of spatial relationships.

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 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; more research needs to be conducted on implementing VR on a larger scale.

Here we present the first description of a large-scale VR deployment 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. 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 was collected on the effectiveness of the course, including student engagement, performance, and student understanding and retention of anatomical spatial relationships.

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?

3.3. METHODS

3.3.1. Ethical Approval

Ethical approval has been applied for through the Institutional Review Board at Colorado State University (CSU; 20-10106H).

3.3.2. Course Structure and Grading

This study was carried out in an eight-week, 75 person undergraduate-level online human anatomy course at CSU. This five-credit hour course consisted of six asynchronous 50-minute lectures each week, two virtual synchronous 30-minute recitation periods, two one-hour synchronous virtual human cadaver laboratory periods immediately following recitation. Teaching assistants (TAs), VR technical support staff, instructors, and professors were present during the recitation and laboratory times.

During the 30-minute recitation period, half of the students attended an instructor-led session via ZOOM, 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. Following recitation, all students completed an online recitation quiz for 15 minutes before beginning their synchronous virtual laboratory sessions. Recitation group assignment (ZOOM vs VR) switched each unit to provide all students equal access to both instructional methods for the recitation sessions.

During the virtual laboratory sessions, students worked together in VR breakout rooms to study a dissectible artist-rendered cadaver. TAs, instructors, and professors were able to join these individual rooms to answer questions. Laboratory sessions were designed to be student-led and self-directed, requiring students to review the material presented in their laboratory guide in assigned groups of four. The laboratory guide was provided by the teaching staff and included important anatomical structures to identify and explore on the virtual cadaver. Furthermore, technical support staff was available for software questions and technical issues. To bolster individualized student learning of laboratory content, TAs facilitated daily "open laboratory hours" each week. During these times, students were additionally able to remotely ask questions. Students were also able to access the virtual cadaver in BanAnatomy program and the VR program at any time outside of formal laboratory instruction hours for independent study and group study. The course was divided regionally into four separate units, organized chronologically as follows: Lower Limb; Thorax, Abdomen and Pelvis (TAP); Head and Neck; and Upper Limb. 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%.

3.3.3. BananaVision and BanAnatomy Program

All registered students received an HP Omen Laptop 17t Gaming, a Samsung Odyssey+ head mounted display (HMD), and two controllers via mail 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 3.1). 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. Uses include surgical planning, surgical simulation, remote and in person anatomical instruction, clinical research, scientific research, patient education/communication, personalized medicine, mass identification and measurement, radiotherapy, measurement for 3D printing, simulations for medical equipment training and more.

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 3.2). 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.

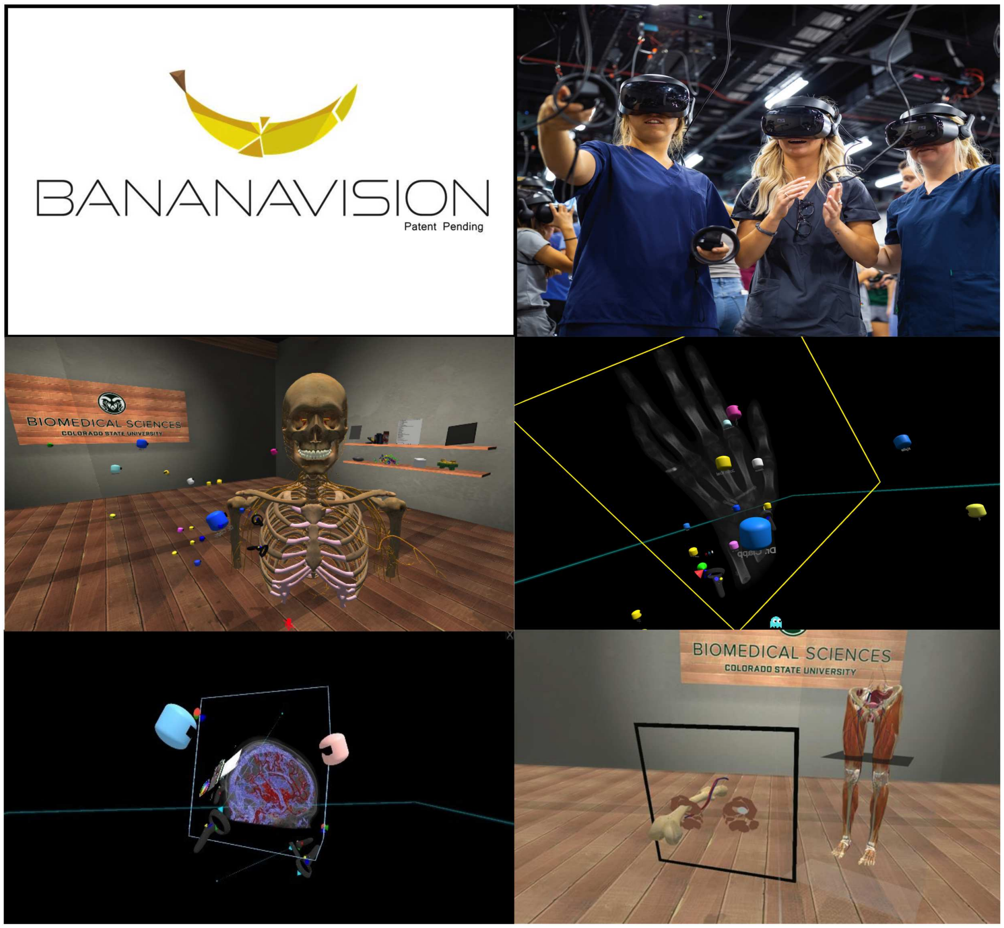

Figure 3.1 BananaVision Software

Images clockwise from top left: BananaVision logo, Students wearing HMD, instructor with several students working in the volumetric scene, cross section function, two students in the volumetric scene, and instructor with several students working on the model data.

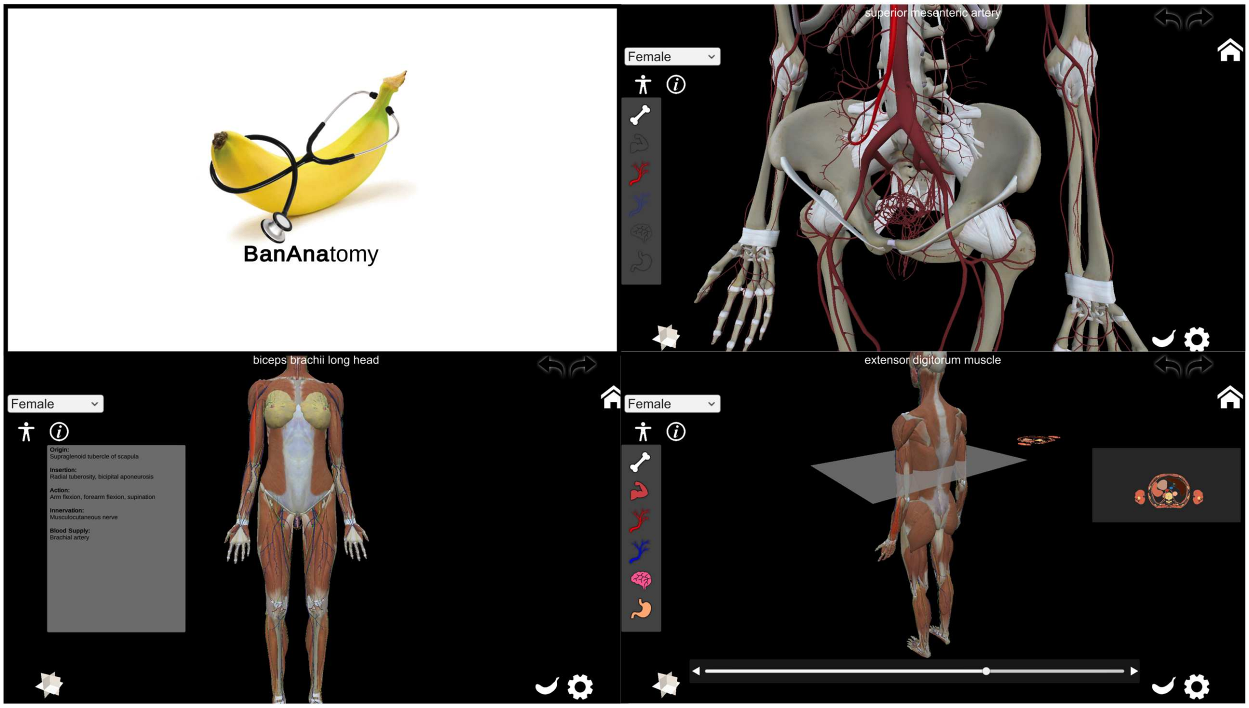

Figure 3.2. BanAnatomy Software

Images clockwise from top left: BanAnatomy logo, isolated arterial system, cross section function, and info panel function.

3.3.4. 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. These critical thinking questions focused on integrating lecture content, such as innervation, attachment, and anatomical function. All questions were open-answer and composed of screenshots of the BanAnatomy program administered via the Canvas learning management system. The exam questions were similar in difficulty level to previous semesters.

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. The majority of lecture examination questions were first-order questions, with few second and third-order questions.

3.3.5. 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 and 30 years old and students were mostly enrolled in undergraduate programs (91%, n = 50, Table 3.1) 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). Extra credit was given to all students for completion of the study components (quizzes and surveys). However, in a pre-survey, students were given the option to consent to use of survey and quiz results for research purposes. Lastly, it was assumed that there was a diverse knowledge background in human anatomy between the students.

Table 3.1 Demographics of Participants Enrolled in BMS 301

	Number of Participants
Health and Exercise Sciences	17
Biology/Biomedical Sciences	14
Human Development and Family Studies	9
Anthropology	3
Neuroscience	3
Biochemistry	2
Other	7

Students had to indicate the pre-survey which major they were enrolled in.

3.3.6. Data Collection

Student examination scores were collected and compared to a F2F section of the course from a previous semester (Summer 2019). Comparison of student outcomes was used to evaluate the effectiveness of the virtual course. Scores from students who completed all examinations were included in this study but were collected in an anonymous manner.

Additionally, the control group used BanAnatomy through ZOOM during recitation, and the experimental group used BananaVision (referred to as the VR group). Quizzes were administered during the first recitation of each unit and questioned student knowledge on spatial relationships in that area. Students were asked to complete a pre-quiz before recitation to ensure 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 3.3). 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 selected their answer using a drop-down menu. All three quizzes contained identical questions. In order to prevent 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 3.2.

Furthermore, this study included a pre-survey and a post-survey administered in the beginning and at the end of the course via CSU's online Canvas learning management system. Data was 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 how confident they were in visualizing objects in 3D. The post-survey focused on their synchronous online attendance, if they missed class and why, how many hours per week they used the programs outside of class, feedback on what they liked and did not like while using the programs, how VR has helped them in learning human anatomy, their interaction opportunities while using VR, their comfort level during these virtual interactions, how confident they were in visualizing objects in 3D, if they would enroll in a VR class as a student again, and what the teaching staff could do to improve future class experiences.

Table 3.2 Example Upper Limb Quiz

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.

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

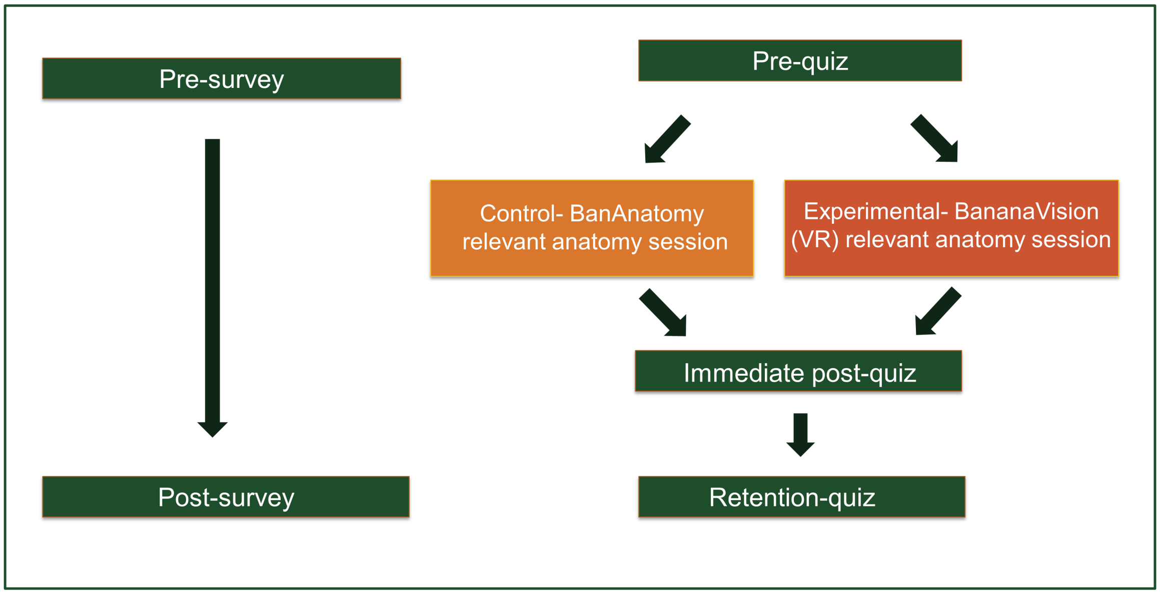

Figure 3.3 Visual for Methods

The study was composed of administering a pre-survey and a post-survey for the collection of qualitative data. For collecting quantitative data, a pre-quiz for testing baseline student knowledge on anatomical spatial relationships was given followed by an immediate post-quiz after recitation and a retention-quiz seven days after the recitation session.

3.3.7. Data Analysis

After the examination scores and quiz grades were collected through the online learning management system Canvas, mean unit examination scores from 2019 and 2020 were compared using an unpaired t-test. Quiz scores (pre-, immediate post-, and retention-quiz) within each group (control or VR group) were compared using a one-way analysis of variance (ANOVA) followed by a post-hoc Tukey test. Quiz scores between the groups were compared using an unpaired t-test. Statistical significance was set at 0.05 level. Unequal variances were assumed 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 and were performed using Microsoft Excel (Microsoft, Redmond, WA) and GraphPad Prism (version 8.4.3 for Mac, GraphPad Software, La Jolla, CA).

After qualitative survey responses were collected, each open-answer question was reviewed individually and once similarities and differences between the participants were identified, the answers were compared and grouped together using an open coding scheme. These preliminary results 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.

3.3.8. Positionality and Trustworthiness

To enhance the quality and trustworthiness of the data, the coding of the qualitative data was 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.

3.4. RESULTS

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

3.4.1. First Research Question

Does this online course provide a comparable alternative to in-person cadaveric laboratories?

In order 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.

3.4.1.1. Previous Semester Comparison

Comparing student examination scores from this study with the students enrolled in the F2F class in summer of 2019 (Table 3.3), statistical analysis indicated that there was no statistical significant difference between the mean scores within the Lower Limb ($t(284) = 1.01$, $p = 0.31$), Head and Neck ($t(284) = 0.58$, $p = 0.56$), and Upper Limb unit ($t(284) = 1.94$, $p = 0.05$). Within the TAP unit, mean examination scores from students enrolled in the online course were statistically significantly better than the mean of those enrolled in the traditional course ($t(284) = 2.34$, $p = 0.02$).

Table 3.3 Statistical Analysis Comparing 2019 and 2020 Examination Scores

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

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.

Comparing the total averaged mean examination score from all units from this study with the total averaged mean examination score from all units from the students enrolled in the F2F class in summer of 2019, an unpaired t-test analysis assuming unequal variances indicated that there was a statistical significant difference between the mean scores in 2020 and 2019 ($t(1142) = 2.71$, $p < 0.01$). The mean for 2020 was 82.27% (n = 544) and 80.08% for 2019 (n = 600).

3.4.1.2. Benefits

When asked in the post-survey (n = 55) how VR assisted in learning anatomy in a multi-select question (Figure 3.4), 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).

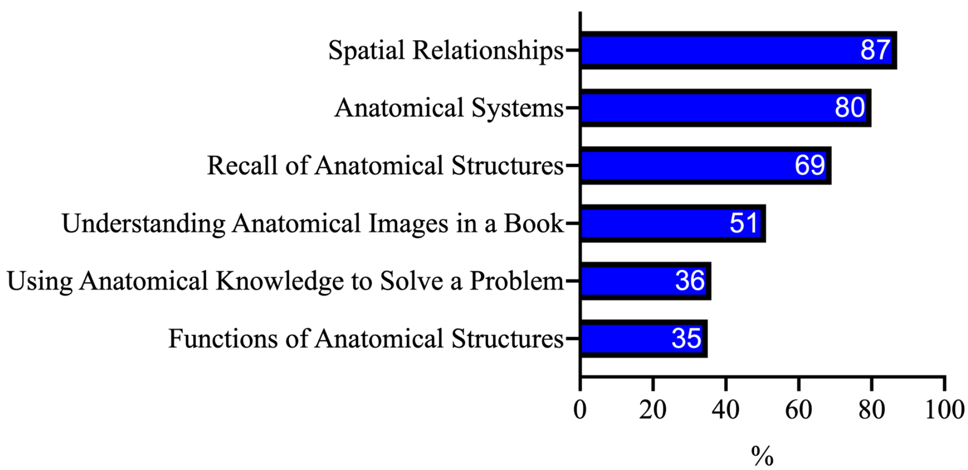

Figure 3.4 VR Assistance in Learning Anatomy

Students indicated in a multi-select question in the post-survey how VR assisted them in learning anatomy.

3.4.1.3. Confidence in Visualizing in 3D

Students reported increase in confidence when visualizing in 3D (Figure 3.5; n = 55). A paired t-test indicated a statistically significant increase between means of pre- and post-survey Likert scale rated confidence ($p < 0.01$). Before the start 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.

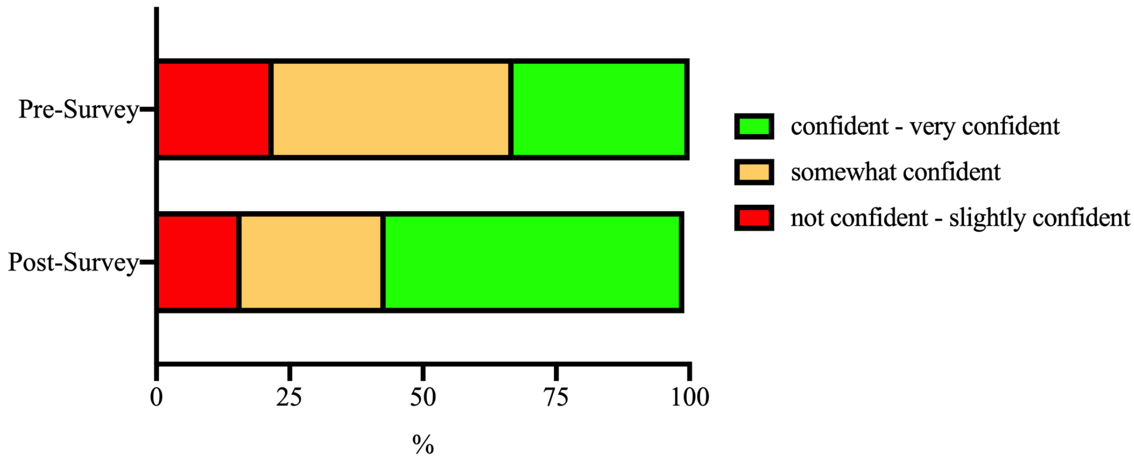

Figure 3.5 Confidence in Visualizing in 3D

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.

3.4.2. Second Research Question

Does the use of VR promote student engagement with peers, instructors and content?

To answer this research question, data on students' perceptions of what they liked and what they did not like about the VR program were collected. Furthermore, students' survey responses about the frequency and comfort level of virtual interactions were analyzed and students were asked if they would enroll in a VR course again to further measure engagement.

3.4.2.1. Student Perceptions of Virtual Reality

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 3.6A). Students most liked the ability to manipulate the virtual cadaver (49%, n = 25) and the immersive nature of the program (38%, n = 21). Students enjoyed 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 3.6B), students notably experienced side effects from wearing the HMD for extended periods of time (>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).

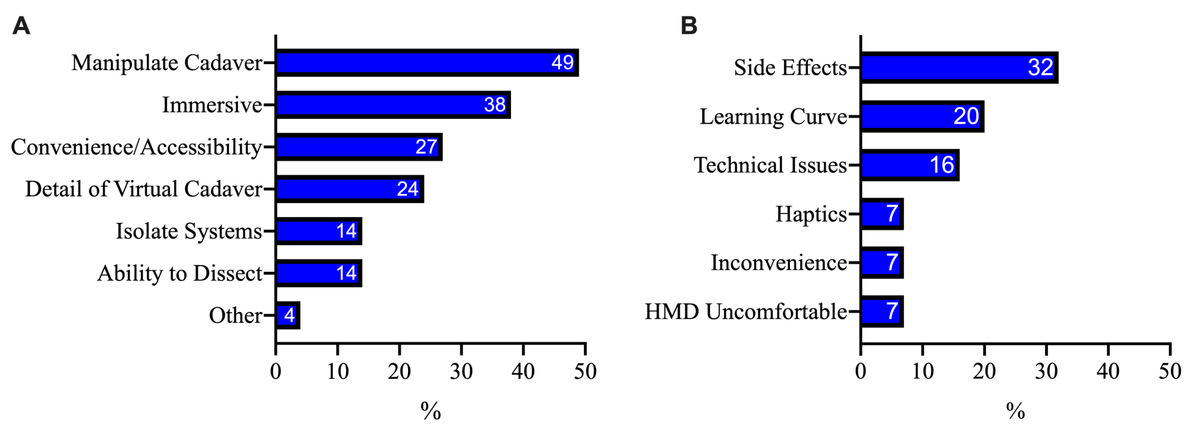

Figure 3.6 Feedback on VR Program

A. Positive feedback. B. Negative Feedback. Students gave positive and negative feedback on the VR program in the post-survey.

3.4.2.2. Frequency and Comfort Level of Virtual Interactions

In the post-survey, students were asked to rate the frequency at which they were provided the opportunity to interact with peers, instructors, TA's, the content, and ability to ask questions (Figure 3.7A; n = 55). Students were further asked to rate their comfort of virtual interaction with peers, instructors, TA's, content, and ability to ask questions (Figure 3.7B, n = 55). Both questions were rated on a 5-point Likert scale. Overall, a majority of students felt that they had either often or very often the opportunity to interact with instructors (31%, n = 17), TAs (66%, n = 36), peers (58%, n = 32), the content (91%, n = 50), and ask questions (67%, n = 37). Some students indicated that they had very rarely to rarely interaction opportunities with instructors (31%, n = 17), 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 instructors (56%, n = 31), 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 instructors (18%, n = 10), TAs (9%, n = 5), peers (16%, n = 9), the content (11%, n = 6), and asking questions (16%, n = 9).

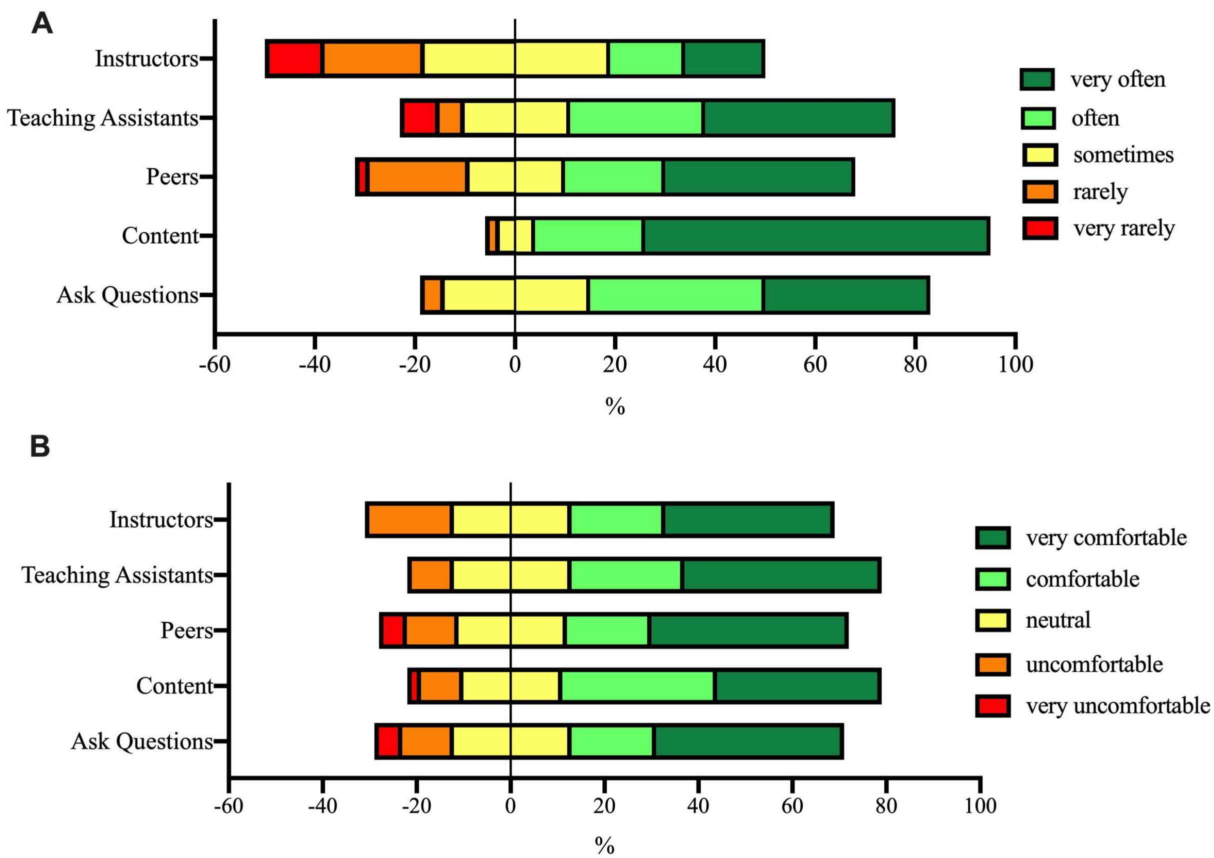

Figure 3.7 Perceived Frequency and Comfort of Interaction Opportunities

A. Perceived Frequency of Virtual Interactions. B. Comfort of Virtual Interactions. Students had to indicate in the post-survey their perceived frequency and comfort of virtual interactions on a 5-point Likert scale.

3.4.2.3. Enrollment

Student post-survey responses (n = 55) were coded using an open coding scheme for the open-ended question "Would you re-enroll in a VR course again?". 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).

3.4.3. Third Research Question

Does the use of VR improve student knowledge acquisition and retention of anatomical spatial relationships?

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.

A one-way ANOVA on the pre-quiz, immediate post-quiz, and retention-quiz within the Lower Limb section of the control group yielded statistically significant variation among the conditions, $F(2,13) = 9.135$, $p < 0.01$ (Figure 3.8A). A post-hoc Tukey test showed a statistically significant difference between the pre-quiz and the immediate post-quiz mean scores ($p = 0.0169$) and between the pre-quiz and the retention-quiz mean scores ($p < 0.01$). There was no statistically significant difference between the mean scores of the immediate post-quiz and retention-quiz mean score. A one-way ANOVA of the VR group also yielded statistical significant variation among the conditions, $F(2,16) = 3.572$, $p = 0.0473$. A post-hoc Tukey test showed a statistically significant difference between the pre-quiz and the immediate post-quiz mean scores ($p = 0.0214$). There was no statistically significant difference between the mean scores of the immediate post-quiz and retention-quiz mean scores nor the pre-quiz and the retention-quiz mean scores. Comparing all control and VR quiz scores, statistical analysis indicated no statistically significant difference between the two groups in their respective quiz scores.

Within the TAP unit, a one-way ANOVA analysis of the control group yielded a statistical significant variation among the conditions, $F(2,15) = 15.69$, $p < 0.01$ (Figure 3.8B). A post-hoc Tukey test showed a statistically significant difference between the pre-quiz and the immediate post-quiz mean scores ($p < 0.01$) and between the pre-quiz and the retention-quiz mean scores ($p < 0.01$). In regard to the VR group, a one-way ANOVA analysis yielded no statistical significant variation among the conditions, F(2,6)

= 0.06667, $p = 0.9296$. An unpaired t-test assuming unequal variances comparing the VR with the control group indicated a statistically significant difference between the pre-quiz mean scores of the two groups ($t(21) = 2.249$, $p = 0.0354$).

There was no statistically significant variation among the conditions within the Head and Neck unit for the control group, $F(2,17) = 1.075$, $p = 0.3396$ (Figure 3.8C), the VR group, $F(2,10) = 1.023$, $p = 0.3608$, and between the two groups within each quiz.

An analysis of variance within the Upper Limb section of the control group yielded statistical significant variation among the conditions, $F(2,15) = 7.369$, $p < 0.01$ (Figure 3.8D). A post-hoc Tukey test showed a statistically significant difference between the pre-quiz and the immediate post-quiz mean scores ($p < 0.01$) and between the pre-quiz and the retention-quiz mean scores ($p = 0.0474$). There was no statistically significant difference between the mean scores of the immediate post-quiz and retention-quiz mean score. A one-way ANOVA of the VR group also yielded statistical significant variation among the conditions, $F(2,8) = 6.435$, $p = 0.0102$. A post hoc Tukey test showed a statistically significant difference between the pre-quiz and the retention-quiz mean scores ($p = 0.0197$). There was no statistically significant difference between the mean scores of the pre-quiz and the immediate post-quiz scores nor between the immediate post-quiz and the retention-quiz mean scores. An unpaired t-test assuming unequal variances comparing the VR with the control group indicated a statistically significant difference between the retention-quiz mean scores of the two groups ($t(23) = 3.333$, $p = 0.0029$).

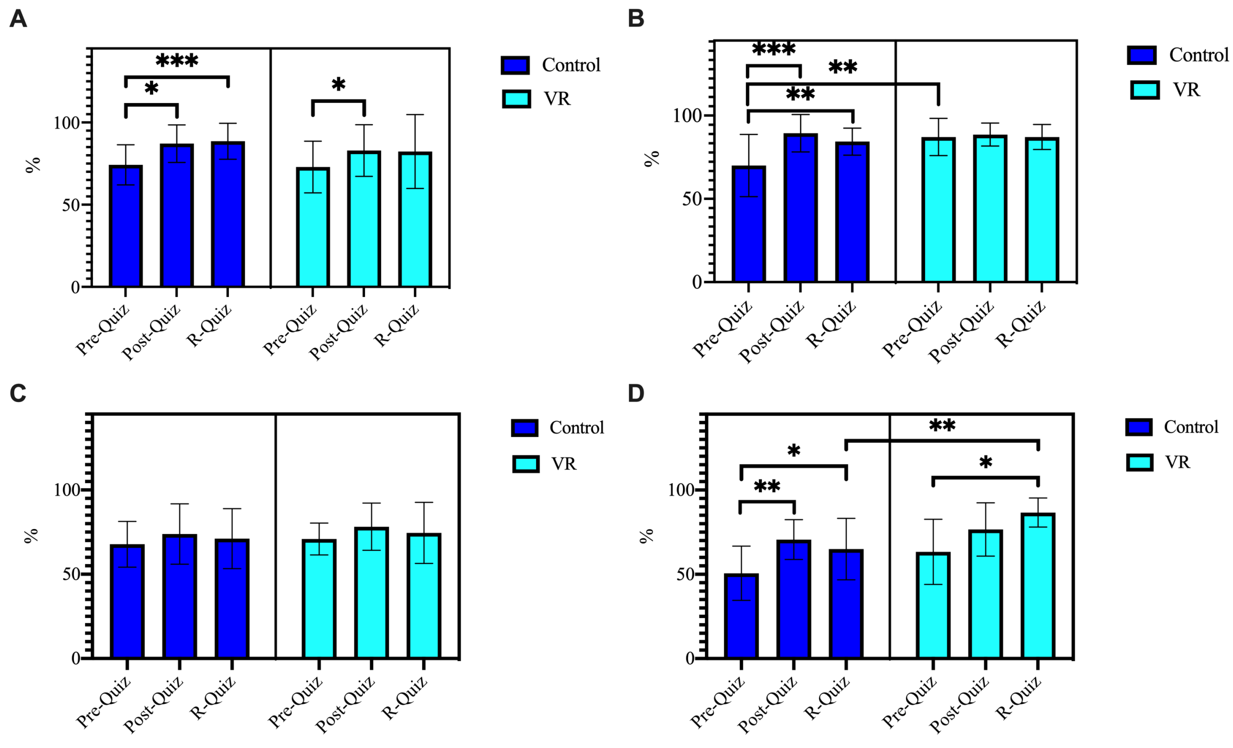

Figure 3.8 Retention within Lower Limb, TAP, Head and Neck and Upper Limb

A. Retention within Lower Limb, B. Retention within TAP, C. Retention within Head and Neck, D. Retention within Upper Limb. R-Quiz = Retention-Quiz. Statistical significance and power indicated by * with alpha = 0.05. Error bars = Mean with SD.

3.5. DISCUSSION

3.5.1. First Research Question

Does this online course provide a comparable alternative to in-person cadaveric laboratories?

Several studies have shown that if online modules are effectively implemented, students demonstrate equivalent knowledge acquisition when compared to F2F instruction [20,24-25,45]. Studies utilizing VR in human anatomy and neuroanatomy courses have reported no difference in quiz scores when compared to F2F instruction [53-55]. 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 3.4) 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 a 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 3.5). 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 [58-61]. 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 [54-55]. 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.

3.5.2. Second Research Question

Does the use of VR promote student engagement with peers, instructors and content?

As identified in previous studies, some online anatomy laboratories struggle to maintain a high level of student engagement and satisfaction [46-47]. 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 3.7). 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 [53-55] 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 3.6). 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 spaces 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.

3.5.3. Third Research Question

Does the use of VR improve student knowledge acquisition and retention of anatomical spatial relationships?

In previous reported anatomy laboratories, students have demonstrated equivalent [53] or greater knowledge retention in anatomical content [54] 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 3.8A). 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 groups for the Head and Neck unit (Figure 3.8B, 3.8C).

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 3.8D). 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 impacted 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 [20,24-25].

3.5.4. Lessons Learned

During the preparation and throughout the 8-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.
- *Make the use of software mandatory.* In this course, the VR program was a supplemental tool to learning anatomy (outside mandatory synchronous VR laboratory sessions) and thus students utilized the program less often later in the semester. Implementing a VR component to graded examinations may increase the use.

- *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 (n = 55), students did not attend some synchronous laboratory sessions due to time conflict (43%), VR side effects (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 connections 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.

3.5.5. Limitations and Future Research

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 software 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.

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.

In the future, we plan to further incorporate the VR software 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 indicated that some students decided not to use the VR program when they faced technical difficulties or discomfort. This needs to be addressed in future classes in order to provide appropriate support to effectively overcome these issues. We 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.

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, we plan to provide additional student support by incorporating additional training sessions into the curriculum in future deployments. These will include live tutorial sessions, recorded modules, and live Q&A office hours. In the future we are interested in investigating the relationship between student 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, we plan to include specific questions to gauge student engagement, perceived usefulness, and satisfaction to better quantify their reactions to using VR to learn human anatomy. Additionally, more qualitative data will be collected in future classes to address further arising problems with technical issues and/or health concerns. To enhance the power of our data collection on knowledge acquisition and student retention, we plan to repeat this study 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.

3.6. CONCLUSION

This study investigating the effects of a large-scale online VR course deployed at CSU demonstrated a positive learning experience that was comparable to F2F instruction in terms of knowledge acquisition. The VR program promoted student engagement and satisfaction with the course, indicated by a high level of perceived frequency and comfort of virtual interactions as well as reported benefits. Students appreciated being able to regularly interact with TAs, peers, and the anatomical content. The ability to extensively manipulate and explore the virtual cadaver were the most liked aspects of the program which were unique to the virtual environment. The indicated increase in confidence of visualizing structures in 3D and understanding anatomical spatial relationships after using the program further adds to the existing literature as there is mixed evidence on the benefits of teaching anatomical spatial relationships using VR. Mixed results showed equivalent retention of anatomical spatial relationships between the groups using BanAnatomy and BananaVision. We therefore conclude that this online interactive course utilizing VR provided a positive and engaging remote learning environment.

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. This study contributes to the existing literature in 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.

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CHAPTER IV – GROUP DYNAMICS IN A CADAVERIC LABORATORY – A CASE STUDY ANALYSIS FOR INSTRUCTIONAL PRACTICES[6,7]

4.1. SUMMARY

This study investigated small and large student group dynamics, personal development, experience, and learning approaches in cadaveric laboratories at Colorado State University and Rocky Vista University. Student interviews (n = 20) and a case study with thematic analysis were performed in conjunction with Forsyth's conceptual framework on group dynamics. Results indicated that both group sizes offer unique benefits and implications. The majority of participants were pleased with their group members in both the small and the large groups but preferred not to study (n = 13) or spend their free time together (n = 15). All students in the small groups (n = 14) stated that they underwent a change in their development as a group member and many have modified their learning strategies. Reported implications of small group work were the increased need for dissection outside of general class time. Students from the larger group indicated that their group size may be more beneficial when students face a large workload outside of the dissection course and when they are not planning on using their dissection skills in the future. However, the use of large groups in the cadaveric laboratory may also reduce students' exposure to the material which could affect their developed learning strategies and developing communication skills with their group members. Overall, students from both groups appreciated a smaller student to cadaver ratio as it provided more time to dissect and opportunities to engage with the material. This study generated findings critical for the understanding of how group work and the selection of group size in the cadaveric laboratory affect students in their learning approach, experience, and personal development. It offers a critical lens for restructuring curricula and incorporating effective methods into the scientific classroom. Educators teaching in any

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[6] This chapter is a slightly modified version of *Group Dynamics in A Cadaveric Laboratory – A Case Study Analysis for Instructional Practices* currently under review in *Journal of Instructional Research*.
[7] List of authors: Heise N, Gupta K, Clapp TR

group-setting should consider these effects to evaluate which group size will generate the desired results for their corresponding curriculum.

4.2. INTRODUCTION

In scientific classrooms, group work has been extensively evaluated and is nowadays one of the most widely used teaching approaches [1]. It can promote students' collaboration and even attitudes towards the studied subject [2-5]. Additionally, it provides opportunities for developing teamwork skills, conflict resolution, and receiving feedback from peers and instructors [4,6]. In contrast to that, ineffective group work could also result in a learning barrier and unequal workload amongst all group members which could eventually influence the quality of work [7]. Measured benefits and implications of group work have outweighed the negative results, and thus been used to change existing scientific curricula especially within undergraduate courses. However, in a graduate or professional level cadaveric classroom, different pedagogical approaches have been mainly studied and assessed over the past decade. Literature has focused on measuring students' perceptions on different online anatomy software [8], integrating anatomy and physiology lectures and laboratories [9], learning anatomy from prosected cadaveric specimen versus plastic models [10], and on flipped classroom approaches [11]. Most studies collected quantitative data such as student outcomes as well as qualitative data in form of surveys and interviews to effectively increase content delivery and students' knowledge acquisition in the classroom. However, when reviewing the literature, there is a lack of analysis on group dynamics and the effects of different group sizes. It remains unclear what additional skills students acquire or if they experience a change in personal development and learning approach while being exposed to different group sizes in human anatomy.

In general, group dynamics are the influential interpersonal processes that occur in the individual group as well as between groups over time [12]. These processes determine how members interact with each other as well as what actions are taken. Aspects like peer pressure and support, power dynamics and leadership, goals and motivations, and structural properties of the group are important to consider when it comes to group work [13]. Structural properties include the group members' content background, time commitment, group size, roles, and group activities. All of these aspects influence how successful a group is and what students learn from each other. Furthermore, Forsyth proposed in his research that there are strong connections between group dynamics, learning, and change in personal development [12].

The researchers of this study, guided by Forsyth's conceptual framework on group dynamics, evaluated how small and large group work in the cadaveric laboratory affect students in their learning approach, experience, and personal development. Using a case study analysis methodology and thematic analysis, group work at Colorado State University (CSU) and Rocky Vista University (RVU) was compared. This study adds to the literature focusing on group learning to support curricular instruction and incorporating effective methods.

Working with cadavers is an expensive undertaking due to high transportation, preservation, and storage costs. As a result, most cadaver-based anatomy classes assign students into groups working closely on one cadaver independently from faculty and staff. Some institutions focus on self-directed group learning whereas others underline the presence of teaching assistants in the laboratory. The benefits of collaborative learning have been well documented in a variety of disciplines [14-17] including anatomy curricula [18-23]. Some of the reported benefits include active learning [16], efficiency in terms of faculty to student ratios [20], students taking responsibility for their own learning [19], and improved student outcomes [19]. Further, group work and peer teaching with cadavers provides the students with the opportunities to develop hands-on, communication, and leadership skills [24].

An example of small group work in the cadaveric laboratory was used in a study by Nwachukwu et al. [25], who used weekly assessments to evaluate the dissection quality of small groups. This study investigated the perception of these weekly assessments and suggested that evaluation of dissection helped the group to use their time effectively in the laboratory and helped them learn anatomy better. Holland and Pawlikowska implemented anatomical case-based learning in the anatomy classroom to facilitate small group learning and evaluated perceptions [26]. However, major results concentrated on discussions while working on these cases rather than overall group dynamics. According to a meta-analysis of STEM courses and programs, Springer et al. found that small group learning settings are "effective in promoting greater academic achievement" and "more favorable attitudes toward learning" [2]. The outcome recommended further implementation of small-group work in undergraduate courses. According to Nieder and colleagues [27], a study on team-based learning (TBL) in a medical gross anatomy course found similar results, although the study primarily focused on student performances and predicting examination scores in order to identify at-risk students. Small group sessions throughout the course included objective-oriented assignments, an individual test, a group test, and a group application problem. Faculty noted improvements in problem solving skills and students' preparedness for the course when exposed to group work. Constant feedback from peers as well as faculty and staff can give each student the opportunity to develop higher reasoning skills [27]. In a study from Vasan et al., test scores improved when medical students were exposed to group work in their anatomy course [19]. Students perceived team-based learning as a motivator to be a responsible team member and to contribute to collective learning by the team. Further, it reinforced self-directed learning and fostered an appreciation for peer respect, both of which characterize adult motivation to learn [28]. According to Johnson and Johnson, students who acquire interpersonal and small-group skills have greater learning, critical thinking and retention [29].

In the lens of the social sciences, Forsyth focused on the nature of groups and group dynamics [12]. He defined and described different types of groups, significance of groups, general group dynamics, and the study of groups. Types of groups include (1) small, unified primary groups, (2) social groups such as work groups and clubs, (3) large collectives, and (4) groups that share a social category (Forsyth, 2014). Forsyth proposed that intergroup relationships increase when the number of group members increases, and he further stated that weak and strong relationships are important in each group to function. Group members follow their individual goals but also seek goals together and can influence each other and the society. Additionally, he stated that studies of groups and their dynamics such as dealing with group structure, performance, and diversity provide solutions to practical problems [12]. Topics in the study of group dynamics focus on "group formation, cohesion, group development, structure, influence, power, performance, conflict, and groups in specific settings" [12]. Figure 4.1 demonstrates a summary of Forsyth's basic structure of groups that no two groups are identical to each other but by definition, two or more individuals are connected by strong and weak relations, seek a variety of goals, create interdependence and cohesion, and are confined by a group boundary.

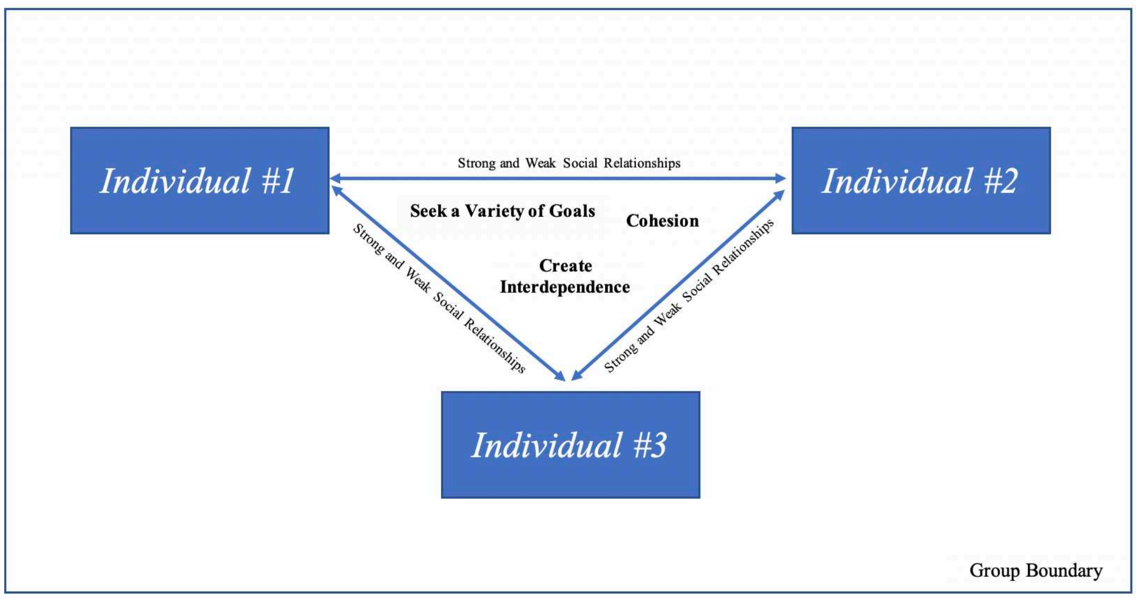

Figure 4.1 Conceptual Model of Group Dynamics

Self-designed conceptual model of group dynamics based on Forsyth explaining the connections between three individuals forming a group [12].

To conclude, even though many benefits of group work in the scientific classroom have been reported, the existing literature lacks an analysis of group dynamics and the effects of different group sizes in the cadaveric classroom. Differences in group sizes might affect their time in dissection, their learning experience, study habits and their overall perception on learning human anatomy. This study offers a critical lens for restructuring existing curricula.

4.3. METHODS

This study is composed of transcripts of 20 interviews conducted in a human dissection course at CSU and RVU. A qualitative case study methodology was used in order to evaluate the group settings. A case study analysis approach was deemed most appropriate for this study as it was used to answer 'how' and 'why' questions in order to describe a phenomenon within its real-life context [30]. This study focused on a descriptive and exploratory analysis of multiple students working in a specific group setting at CSU and RVU as it was important to consider the context within it occurred [30-31]. Ethical approval has been granted for through the Institutional Review Board at CSU (19-9405H).

At CSU in Fort Collins, CO, faculty and staff implemented group work into the curriculum of a graduate level human anatomy dissection course with the hope to transform human anatomy instruction in the laboratory into a more active learning and self-directed environment. Students in groups of four were required to complete a full cadaver dissection over one semester. This approach was coupled with group tests with the intent to enhance learning and the overall understanding of human anatomy. Faculty and staff at RVU in Parker, CO, have a similar approach in which groups of 12 students enrolled in the Physician Assistant (PA) program or Master of Science in Biomedical Sciences (MS) program completed a full cadaver dissection.

This case study analysis compared these two laboratory settings and explored the benefits and implications of different sized dissection groups. The following research questions guided the study:

1. What are the group dynamics in a cadaveric laboratory setting?
2. How do group dynamics in a cadaveric laboratory influence the students' personal development as a group member?
3. How does a 4:1 and 12:1 student to cadaver ratio impact students' experience and preference in terms of learning human anatomy?

We applied Forsyth's conceptual framework to the group work in the cadaveric laboratories of both universities [12,32]. According to Forsyth, group dynamics are the influential interpersonal processes that occur in the individual group as well as between groups over time. Here, we focus on the dynamics within an individual group. His conceptual framework helped define relevant variables for this study and how they might relate to each other. The explanatory variables were structural properties of the group such as group size and how they were formed, time spent in the laboratory, leadership roles, and group activities. The response variables were overall group dynamics, experience within the course, and change in personal development. Based on this framework, we investigated whether a smaller student to cadaver ratio would increase cohesion, success and thus more positive group dynamics and change in personal development.

4.3.1. Participants

All registered students at CSU and RVU who expressed interest in giving an interview formed an opportunity sample for this study (n = 20; Table 4.1). They were recruited via an oral script and volunteered their time to participant in the study. Overall, the interviewees were chosen from different groups based on maximum variation sampling which "selects cases that cut across some range or variation" [33]. In detail, the focus for the selection at CSU was on choosing male and female students as well as undergraduate and graduate students in order to increase the variety of backgrounds and opinions about the group work. The age range of the participants was between 20 and 35 years old and most students at CSU were enrolled in a graduate or undergraduate level program in either Biomedical Sciences, Biology or Health and Exercise Sciences. At RVU, although the groups had a mixture of students from different programs, only the PA students were interviewed. Lastly, none of the students at CSU had experience with taking any dissection coursework before enrollment, but a few at RVU had taken a dissection course before. One participant at RVU completed the dissection course at CSU prior to attending RVU and thus was dissecting a cadaver for the second time. There was about an equal number of students who identified as male or female enrolled in the two courses, but more females were interested in being a participant in this study.

Table 4.1 Demographics of Participants

	CSU		RVU
Gender	5 males	9 females	6 females
Education Level	7 undergraduate students 7 graduate students		6 physician assistant students

Participants were asked if they identified as a female or male and if they were enrolled in an undergraduate, graduate or physician assistant program.

4.3.2. Course Structure and Procedure

In the fall semester of 2017 and 2018, around 50-60 students enrolled in the graduate human dissection course at CSU and dissected 14 cadavers in groups of four. Each group was assigned to a specific cadaver and worked daily on designated anatomical regions. The course was organized into four dissection blocks: lower limb, thorax and abdomen and pelvis, head and neck, and upper limb. Each block was approximately four weeks long and composed of weekly quizzes and one laboratory examination that tested students' knowledge. The course met three times a week for three hours each with the presence of professors, instructors, and teaching assistants. The anatomical areas that needed to be dissected varied in size, difficulty, and detail, and it was required that each student contribute equally. It was the group's responsibility to coordinate time for dissection after hours and on the weekend.

At RVU in the fall semester of 2019, around 70 students enrolled in the professional human dissection course dissecting six cadavers in groups of twelve. All students were working on their assigned cadaver for two hours every other week with the presence of professors and post-doctoral fellows. The course was similarly organized in dissection blocks in which each student group had to dissect a few weeks long on the lower limb, thorax and abdomen and pelvis, head and neck, and upper limb. Each block was composed of weekly quizzes and one laboratory examination that tested students' knowledge. However, students were not required to dissect outside of general class time as most dissections were completed during class.

4.3.3. Student-to-Cadaver Ratios

Student cadaver groups at CSU were assigned with a ratio of 4:1 meaning that four students received one cadaver to work on. These group assignments were made by the students themselves and did not follow any rules or patterns. Each group received a cadaver for the semester to work on which resulted in a total of around 14 groups of four students.

Student cadaver groups at RVU were assigned with a ratio of 12:1 meaning that 12 students received one cadaver to work on. However, they were further divided into groups of three to dissect in timed blocks for two hours every other week. These group assignments were made by the instructors and based on prior dissection experience. This division resulted in six groups of 12 members each or 24 groups of three members.

4.3.4. Data Collection

The data collection was driven by Forsyth's conceptual framework on group dynamics and focused on the structural properties of student groups including group size, roles such as power dynamics and leadership, as well as student interactions and how group members influence each other [12]. All of these aspects were applied to the learning environments at CSU and RVU in order to support the theoretical understanding of groups. For this study, 14 interviews at CSU and six interviews at RVU were conducted. In fall of 2017 and 2018, we conducted seven interviews each year at CSU which took place towards the second half of the semester. These interviews were dispersed throughout multiple weeks. At RVU, we conducted six interviews on one day, which took place during the last week of their dissection course.

In general, the entire data collection took place while the primary researcher was a participant-observer in the cadaveric classrooms. Since notetaking or audio recording was prohibited in the classroom, the primary researcher dissected with the students for at least an hour to build rapport and observe and evaluate what program each student was enrolled in at RVU. Interview questions were then asked in a private setting after the dissection.

The following interview questions were used in order to explore the group dynamics in the cadaveric laboratory (first research question):

- Within your group, do you or your members identify yourselves with a specific role? Given answer choices were leader, active member, teacher, work bee, motivator, quiet observer, and slacker.
- How would you in general describe the dynamics in your group?
- Do you study together or do something fun outside of class?

Furthermore, the following questions were asked in order to explore how the group work influenced their personal development as a group member (second research question):

- Have you learned something about yourself throughout this group work?
- Would you say your experience will influence future group work?

In addition, the following interview questions were posed to explore student-to-cadaver ratios and student learning in the content of human anatomy (third research question):

- Do you like your group size, or would you change it?
- What if the student-to-cadaver ratio was bigger or smaller?

Lastly, additional questions were asked to start or end the interview and to explore further structural properties:

- How did you form your group?

4.3.5. Data Analysis

Data from this study were largely analyzed through the lens of a case study as it compared students' experiences of group work within two contexts. It built a descriptive, multi-dimensional framework for later analysis. With that, the interviewees' answers from CSU and RVU were transcribed, analyzed, and compared. The transcription process focused on major informative points stated by the interviewees. No voice pauses or colloquial terms were analyzed since the linguistic aspects did not contribute to the overall goal of this study. As transcripts were read and compared to notes, data were coded, and categories and themes constructed. Once similarities and differences between the interviewees were identified, the answers were compared and grouped together while using an open coding scheme. These preliminary results were then reviewed during the phase of axial coding as repetitions of codes were searched and connected [34]. Finally, those merged codes assisted in answering the research questions. Quotations supporting the data were edited for grammatical errors.

4.3.6. Positionality and Trustworthiness

To enhance the quality and trustworthiness of the data, the data collection was member-checked after transcription of each individual interviewee. The positionality of the primary researcher added to the trustworthiness in a way that she was a teaching aid in the dissection courses at CSU and had been working as a Graduate Teaching Assistant for multiple years. She also worked with the students at RVU in their dissection laboratory prior to the conduction of the interviews. She had an extensive background in human anatomy and cadaveric dissection that might have contributed to the formation of rapport and trust with the students. Since she was exposed to the group work herself years prior, she was familiar with the students' perspectives throughout the study. This similar experience may have negatively influenced the trustworthiness of the study as such work may be seen as a possibility for bias, themes, and the choice of interviewees during the study.

4.4. RESULTS

The findings concluded from this study were based on the analysis of the categories and themes that arose during the 20 interviews. Brief descriptions of main themes were supported by citations from a few participants who preferred to stay anonymous. Structural properties of the groups were determined first, and the rest contributed to answering the research questions.

4.4.1. Structural Properties of Groups

At CSU, group members self-selected at orientation day prior to the start of the course. Results indicated that seven out of 14 students did not know anyone prior to the course (Theme: “Random”). Two students had already determined their group members beforehand (Theme: “Formed Before”). The remaining five students said that they had met at least one person before taking this course and thus had a mixture of random and planned group members (Theme: “Mix”). Students at CSU were allowed to form mixed groups of undergraduate and graduate students (Figure 4.2A).

At RVU, students were not allowed to self-select their group members as faculty made group assignments prior to the start of the course based on the students’ dissection experience (Theme: “Random”). Each group had at least one member of the PA and one of the MS program. Since the students shared other courses as well, some students already knew each other upon the start of the dissection.

Students at both schools were then asked to state their self-identified group role from a given list. Results indicated that eleven out of 20 indicated that they put themselves into a leadership role and had either continued that position throughout the course or had stepped back a little bit in certain dissections. A leader by definition is a person who organizes a group and makes the majority of decisions. Some stated that they naturally fall into leadership positions when it came to group work as they tended to coordinate and schedule tasks. Being a work bee was the second most popular role chosen by the students, followed by three active members and two teachers (Figure 4.2B). A work bee was described as being in the laboratory and dissecting often. An active member was open to being told what to do and completing the assigned task. Teachers were students who enjoyed quizzing the other group members or shared their knowledge while being in the classroom. Motivator, quiet observer, and slacker were not selected.

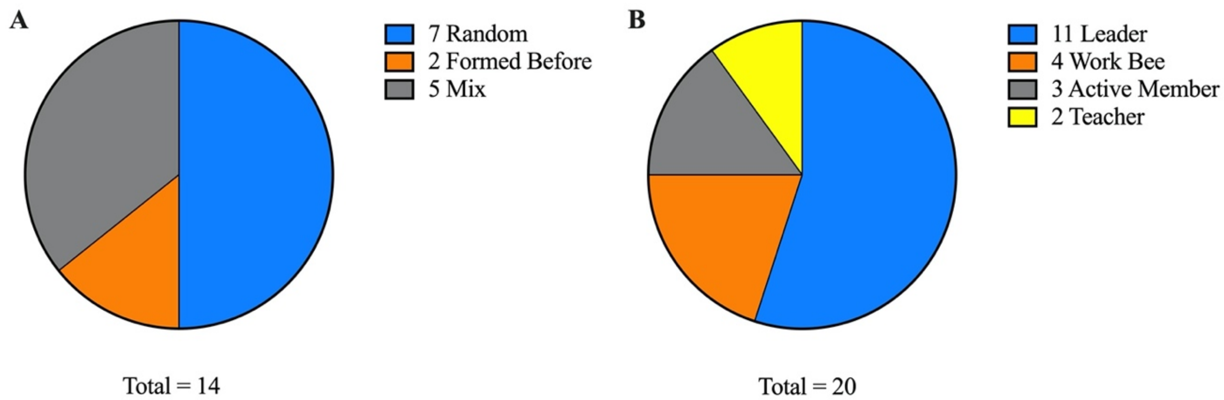

Figure 4.2 Formation of Group at CSU and Identified Role Within Group at CSU and RVU

A. Students at CSU indicated if they randomly formed or got put in a group, had formed their group before the course started, or if it was a mixture of both. B. Students at CSU and RVU had to state their role within their respective groups from a given list.

In terms of group activities at both schools, eleven participants denoted that they neither studied with the other group members outside of class nor spent their free time together in doing something outside of academia (Figure 4.3). Observed themes were noted based on if the students spent time together outside of class, seldom, or none. Some have tried to arrange meetings, but different scheduling of courses and private life made it hard for those who were interested. One participant stated, "it might help group dynamics if [the group] spent more time [together] outside of dissection". However, most of these eleven participants shared that they had regular meetings with members outside their group in order to get to know the other class members more or to have some time away from the group they were in. One participant who was not content with his group explained he was "going to look out for [himself] and [his] grade" as he felt that the others were not putting in the same effort as him and thus preferred not to study with them. He also stated that this course was an honor for him and that he had "kind of gravitated more towards the groups that [were] strong studiers, that [were] serious about this, that [were] here for the right reasons" when it came to spending their free time together. Others had seen each other outside of dissection on rare occasions and had mentioned that they study together around examinations or quizzes to review the content of human anatomy. Less than 40% of the students stated that they had set study hours together and frequently did something outside of academia. They indicated that they had become friends and that they also helped each other out outside of dissection in other courses or in their private lives. The sharing of learning strategies across the interviewees were not mentioned nor reported as valued and important.

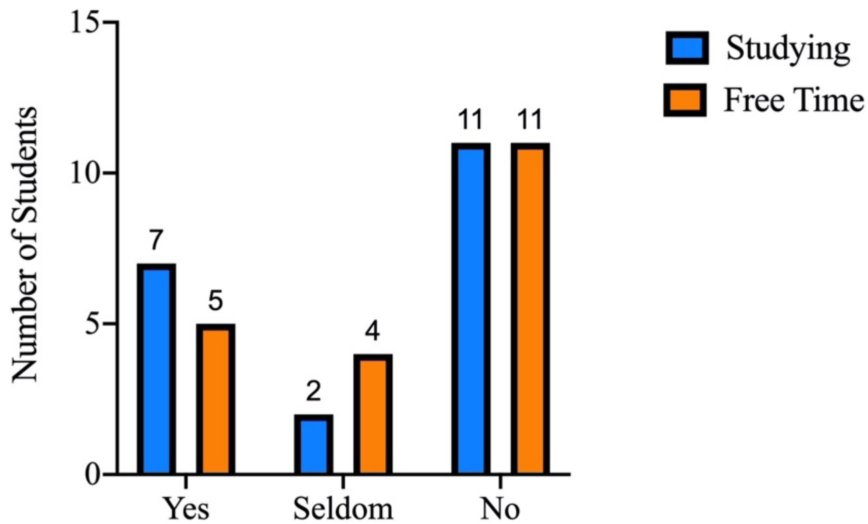

Figure 4.3 Group Activities

While some students participated in group activities, the majority reported spending no time in group activities during studying or free time.

4.4.2. Research Questions

What are the group dynamics in a cadaveric laboratory setting?

The overall group dynamics differed amongst the participants and themes that arose were being "satisfied" with the group" and "unsatisfied". At RVU, the PA interviewees appreciated the mixture of students as every member was able to contribute to the dissection differently due to their educational background and other courses, they were enrolled in. In their groups of three, they would talk about school, learn from each other, and help each other out in their private life. It was stated by only one participant that it was uncomfortable at times as members tended to quietly work for the two hours. Occasionally, they would chat about academic topics, but since they would not see each other often, they preferred to just stay focused on the dissection. In respect to their groups of 12, little to no communication was present amongst the interviewees as they would only see each during the overlap of their assigned dissection times. One reported that she did not feel like she was part of a group as the times were so split, and no one would come dissect outside of general class time. Sometimes she would ask the other groups a few questions when she studied for exams. However, overall, everyone was pretty satisfied with their group and their dissection work.

At CSU, interviewees extensively elaborated on how the dynamics had changed to the positive throughout the semester. Similar to RVU, the mixed groups of graduate and undergraduate students reported that it was nice having group members with different backgrounds. Many students from both universities mentioned that it was hard figuring out strengths, communicating with each other, and making schedules to dissect outside of general class time. One undergraduate participant who had a stronger background in human anatomy than her other group members mentioned that it took some time for her to feel like a cohesive team as stated in the following excerpt:

> At the beginning, all three of my group members […] were scared they would disappoint me […]. Now it feels like [..] we are all working together towards the goal. I think a lot of it also comes with trust […], them trusting themselves to be able to know things and do things. (Anonymous student #1, personal communication, October 13, 2017)

As the semester progressed, CSU interviewees stated that the experience had been positive, conflict free, cohesive, and productive as initial power struggles were eliminated. Some students even became friends with their group members and tried to enroll in future courses together. One participant stated that the many hours per week dissecting a cadaver motivated him to engage with his group and work on issues that arose. Nevertheless, three participants were not very satisfied with their group. One participant was frustrated with no system in place to hold individuals accountable for equal work and proper dissection. He reported the number of hours he dedicated negatively affected his time to study outside of class. None of these negative experiences were reported by the participants from RVU.

How do group dynamics in a cadaveric laboratory influence the students' personal development as a group member?

Amongst all 20 interviewees, 85% indicated a change in personal development. All participants implied they had mentally grown throughout the course and learned something about themselves. They reported these experiences would be beneficial for future professional group settings. The students were directly asked if they experienced a change in personal development to answer this research question.

At RVU, one participant mentioned that she generally enjoyed group work but had never been super pro-active. She tended to defer to others but said that she had been more hands-on with this dissection project and had taken on tasks more than she had in the past as seen in the following excerpt:

> Being in this smaller group [of three] made me realize that I can and I should jump and put myself out there […]. I find myself just jumping in and doing things more often than I would just because I can. (Anonymous student #20, personal communication, December 5, 2019)

She emphasized all these experiences will influence and affect future group work assignments. One other participant from RVU mentioned learning how to step back at times and another that the enthusiasm for group work had gone up. The remaining students stated that it was a unique group setting but did not change prior outlook. The student who completed CSU's dissection prior to attending RVU revealed that she had to change her expectations drastically throughout the semester as the curriculum at RVU differed so much from what she was used to at CSU. She learned how to express her expectations to her group members but also how to adjust them more effectively.

Most participants at CSU mentioned a lot of change in their personal development. Many endorsed in their interviews an increase in communication skills, conflict resolution, and their ability to trust people. Additionally, they reported learning how to express expectations in a workplace as the dissection of a cadaver was seen as a project close to what they may experience in a future health profession. This is demonstrated by the following excerpt:

> Not everybody is the same […] but that is okay […]. And it is good to kind of struggle with this because there are always going to be group settings no matter where you go […]. It is okay to fail sometimes […]. (Anonymous student #3, personal communication, October 20, 2017)

Similar to RVU, one CSU participant mentioned he learned stepping back to take a follower role instead of a leader as seen in the following excerpt:

> When I was in Nebraska [for military], we were always put in a leadership role […]. Having this class […] you really need to know when to take a step back and just be told what to do because if everybody tried how to delegate things, then no work is ever going to get done […]. I am a lot more comfortable [now] in a follower role. (Anonymous student #4, personal communication, November 29, 2017)

Additionally, participants at CSU reported a change to their studying and learning approach. They believe they learned how to study smarter and go beyond what they thought they could handle in terms of workload as seen in the following excerpt:

> I know for sure that the way I have approached learning has changed […]. In the past, […] I [would] just memorize [information] and not think about how it relates to each other […]. But then here with this [course], I really learned to take these things […] and just look at them as systems […] and not so much to memorize everything and make connections. (Anonymous student #13, personal communication, January 31, 2019)

How does a 4:1 and 12:1 student-to-cadaver ratio impact students' experience and preference in terms of learning human anatomy?

When asked if the participants enjoyed the amount of people in their group, four at CSU compared to 12 at RVU, all CSU participants indicated that they preferred the small student-to-cadaver ratio as it provided them the opportunity to be a part of every dissection (Theme: "Small S:C Ratio"). They mentioned that the workload was doable but that it could get crowded during small areas of dissections, such as the head and neck, when really only one or two students were able to dissect at the same time. The interviewees referred back multiple times to the extensive group work contributing to the development of useful group skills. When prompted about what it may be like working with a bigger group, all 14 CSU interviewees agreed that the learning opportunities and experience would decrease. They feared missing out on dissections and other workload challenges that drive extensive communication skills to produce a cohesive group.

Similarly, RVU students noted that the groups of three were beneficial as two could dissect at the same time while the other studied. One participant mentioned that "three ha[d] been good because [they got] to do more […] and learn more at the same time”. Comparing that with the group of 12, two participants stated that studying had been harder because they only got to dissect every other week missing out on some of the dissected areas. This is demonstrated in the following citation: “I feel like there is a lot missed when people are dissecting different [areas] that we don’t get to dissect […]. That knowledge does not really come together for me until I am preparing for the practical [examination]”. The participant who took the dissection course at CSU prior to attending RVU was able to compare both curricula and student-to-cadaver ratios. She was excited that she got to dissect again at RVU after graduating from CSU, but she was sad that the groups were bigger and that she did not get to complete a full cadaver dissection again as seen in the following excerpt:

> That [course at CSU] was one of the most incredible experiences I am ever going to have in my life. Having four people on one body from start to finish in one semester […]. You got to take such an active role in every single part of the dissection and you have to know your group members so well […]. [At RVU], I wasn’t able to dissect the heart because it was not on my week. (Anonymous student #15, personal communication, December 5, 2019)

Two participants at RVU were not bothered by the bigger group dissection (Theme: “Large S:C Ratio”). One student pointed out the larger group allowed her to focus on other coursework demands. The other mentioned the actual dissection did not matter to her, she was glad to have a reduced workload.

4.5. DISCUSSION

The researchers of this study, guided by Forsyth’s conceptual framework on group dynamics, evaluated how small and large group work in the cadaveric laboratory affect students in their learning approach, experience, and personal development. Here, we suggest small and large group work in a science classroom has unique benefits and implications and offer a critical lens for restructuring curricula and incorporating effective methods. Although the group dynamic results varied slightly between the different locations, overall, the findings were similar (see Figure 4.4). Students at RVU and CSU were either randomly placed in groups or had previous knowledge of classmates to choose groups. More students in the small groups at CSU took the leadership role compared to RVU. Time spent studying and free time showed mixed results between groups in the two locations. The majority of students at CSU and at RVU indicated that they experienced a change of view and personal development through the group work in the cadaveric laboratory and most students preferred a smaller student-to-cadaver ratio.

In general, the groups settings at CSU and RVU can be defined by Forsyth conceptual model as a mixture of primary and social groups. A primary group is defined as a "small, intimate cluster of close associates" such as peers [12]. They are connected by frequent interaction through many face-to-face settings. A social group is larger and often task-oriented such as seen in study groups [12]. The purpose is to complete a task instead of forming strong relationships. Based on the time the students spent to together in class and the mutual task of dissecting a cadaver, it can be concluded that CSU's group setting is a bit more personal and time intensive when compared to RVU's group setting. This might have influenced the dynamics observed at both schools.

At CSU, dynamics varied between the groups and corresponded with the amount of dissection hours they put in outside of general class time as well as the success in the course itself. The data on group size was inconclusive due to a lack of quantitative data analysis; however, it could be speculated that if a group received good grades, students were more eager to spend time with group members. Their reported reasoning cited similar engagement and effort as one participant stated he had "gravitated more towards the groups that [he knew were] strong studiers, that [he knew were] serious about this." Spending abundant time together outside of scheduled hours to dissect influenced students' personal development. Students reported this time developed study skills and ways to become a responsible group member. This idea of being motivated to become a responsible group member and expression of peer respect is supported by the literature [19]. The interviewees also learned how to adapt and communicate expectations in order to be a higher functioning group. This finding supports Johnson and Johnson [29] that frequent group work can result in a change in personal views and development. Further, this is also supported by Forsyth's conceptual framework on group dynamics. He stated that people individually seek their own objectives, but group settings can constrain and guide them [12]. As seen CSU, all participants experienced a change in personal development due to being exposed to large and small group settings respectively. Students have learned how to approach conflicts and how to change their study habits based on their group dynamics.

Conversely, it appeared that such group work did not necessarily endorse the sharing of learning strategies, nor an increase in social interactions outside of the classroom. Vasan and colleagues [19] described that students exposed to group work are more likely to experience self-directed learning and collective learning by the team. Furthermore, based on Forsyth's conceptual framework, we suspected that a smaller student-to-cadaver ratio would cause increased cohesion, success, and more positive group dynamics with changes in personal development. Here, however, only half of the CSU students indicated they studied course material outside of scheduled class time together. Most of that studying was content related and no study strategies were shared. This may have been due to the smaller groups having a larger volume of work per student. Additionally, these students were navigating a new paradigm with an enormous amount of small group work. Their unwillingness of sharing strategies may be due to their lack of confidence in this paradigm. It was stated numerous times that learning strategies formed previously in undergraduate studies did not apply in this course. Over the course of the semester, participants changed their learning approach from rote memorization to forming connections within the presented material. The remaining participants preferred studying alone or with members of other groups reporting this was their most effective use of time outside of their shared dissection hours as seen in the following citation: "It's hard [to all get together and study] because we are all on different schedules."

In contrast, the group dynamics at RVU were generally positive amongst the participants throughout the course. Even though students did get along well, it was mentioned multiple times they were facing a large workload from other courses while being in the dissection course. These students were not required to dissect outside of general class time and spent less time together, which may have contributed to the lack of getting to know the group members in a more personal manner. Forsyth's description on social groups supports this finding. He proposed that members of social groups are task-oriented and mainly focus on their assignment rather than developing extensive relationships. Surprisingly, we found the larger student-to-cadaver ratio at RVU resulted in an overall more positive group dynamic when compared to CSU. The RVU students reported spending less free time as well as less group studying for dissection. However, most participants mentioned that they worked together in other courses which could have been a result of the positive group dynamics in their dissection course. Based on the RVU interviews, there was little change in personal development reported. This contrasted with the CSU findings. The difference could have been due to the larger group size at RVU. The literature suggests that student performance increases in line with group size until groups have five members [35]. Treen and colleagues suggest that in large groups, students may not be able to give the material the attention it deserves. Group coordination, collaboration, and teamwork may suffer as groups become bigger [35]. Additionally, RVU participant believed this project was comparable to past group work experiences whereas a CSU student described the dissection course as the "ultimate group project". It appeared the more time invested in dissecting the cadaver, the more reflection, and changes in personal development were reported.

Juxtaposing their preference of group work versus individual work with the overall group dynamics and free time spent with their group members with, no conclusive results were observed at both schools suggesting that their prior preferences had only minimal effect on their experience.

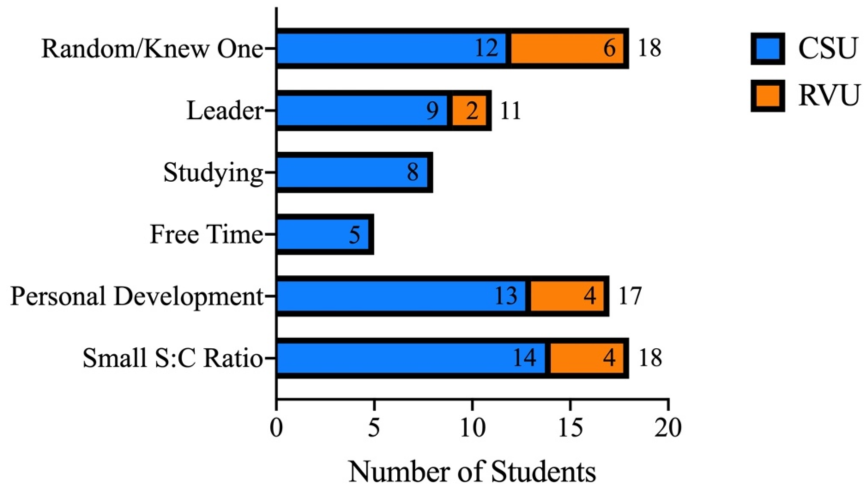

Figure 4.4 Overall Trends at CSU and RVU

Comparison of all 20 interviewees from CSU and RVU. Random group or knew least one other student, assigned themselves the role as the group leader, studied with group members outside of general class time, spent free time together as a group, experienced a change in personal development, and preference of student-to-cadaver (S:C) ratio.

4.5.1. Limitations and Future Research

There are a few limitations to consider. Both institutions involved in this study use clinical examples to demonstrate anatomical importance, however, the CSU faculty have a more academic focus while RVU faculty have a more clinical focus. For example, the weekly quizzes conducted by CSU faculty graded both the quality of the dissection and the anatomical knowledge of the group. Whereas the weekly quizzes at RVU were graded on the students' knowledge of clinically relevant anatomy and did not focus on dissection quality. This was stated by a participant who had completed CSU's dissection course before attending RVU. This likely influenced the dissection quality of the participants at both institutions and ultimately may have had an effect on how much time they spent dissecting during and outside of general class time. One participant stated that CSU's dissection course was "the hardest thing [she had] done". The time-consuming group dissection found at CSU (around 30-40 hours per week) with the goal of high-quality dissections may have created increased group pressure. Students at RVU commented that they would have not been able to keep up with the dissection and their other courses if the dissections hours per week were longer.

Additionally, RVU's group members were predetermined to randomly assign students to a group. This demonstrates a limitation as it is hard to evaluate how the CSU students' choice of group members had an impact on the overall results. Future studies focusing on predetermined groups only would enhance the data and aid in juxtaposing the results.

Another limitation is the difference in the number of participants at CSU compared to RVU. At CSU, the primary researcher was able to conduct this study over multiple semesters. The CSU interviews were spaced out which might have contributed to the establishment of increased rapport and trust with the students. At RVU, only one visit was scheduled, and all interviews had to take place on that day which may have influenced the quality of the interviews performed. Detailed demographic aspects as well as in-depth background research of the participants could be considered to enhance the power of this study. Further, it would be beneficial to interview all members of the same group in order to examine values, beliefs, and thoughts of the participants. Focus group interviews could be conducted in addition to individual interviews. Finally, dissection groups with a higher student-to-cadaver ratio could be implemented into the same classroom to further compare the similarities and differences between individual group sizes.

4.6. CONCLUSION

This study showed that different group sizes have an effect on the students' personal development, learning strategies, and overall experience in a cadaveric classroom. This study revealed the importance of considering group sizes in the cadaveric classroom. Educators need to evaluate which group size will generate the desired results for their corresponding curriculum. Most cadaveric classrooms focus on knowledge acquisition as some students might never need their dissection skills in their future careers. However, additional non-academic skills that are hard to measure should be taken under consideration when setting up a curriculum. For example, working in health care requires constant team building and conflict resolution in order to provide efficient care for those in need. Nurses, physicians, and professionals of different specialties must work effectively in a team, communicate, and share their resources in order to solve health problems [36].

A smaller student-to-cadaver ratio as seen at CSU may support a bigger change in the students' personal development as a group member, learning strategies, and an increased exposure to the learned material. However, small group work in the cadaveric laboratory may require more time for dissection outside of general class time, and less students being able to enroll in the course. Faculty working with many smaller groups might have an increase in workload as they are trying to address each individual student. A bigger student-to-cadaver ratio as seen at RVU may be more beneficial when students face a large workload outside of the dissection course and when they are not planning on using their dissection skills in the future. It further enables more students to enroll in a course. Even though, large group work may still result in some change in personal development, the decreased workload may also reduce students' exposure to the material which could affect their developed learning strategies and developing communication skills with their group members. Faculty working with many larger groups might be challenged to address each student individually.

In this study, we suggest small and large group work in a cadaveric classroom has unique benefits and implications and offer a critical lens for restructuring curricula and incorporating effective methods. It provides valuable information that can be applied to medical schools which have implemented cadaveric instruction into their curriculum with the need to better understand the impact of group dynamics on adult learners. Overall, the courses at CSU and RVU were designed to address the enrolled students as adult learners. The adult learner is selective, self-directed, brings previous knowledge and experience to the classroom, and is often interested in content that has direct application to their lives [37-38]. The curriculum at both schools may have contributed to the observed benefits and implications of small and large group work in these courses. These connections to adult learners and curriculum could guide future studies and contribute to the need in how to effectively address the adult learner in STEM classrooms. Besides informing educators in the anatomical sciences, other classrooms using group learning would benefit from this analysis to evaluate which group size will generate the desired results for their corresponding curriculum.

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CHAPTER V – A SYSTEMATIC APPROACH TO SOLVING NOVEL PROBLEMS IMPROVES CRITICAL THINKING SKILLS[8][9][10][11]

5.1. SUMMARY

Both research and practical experience in education support the use of case studies in the classroom to engage students and develop critical thinking skills. In particular, working through case studies in scientific disciplines encourages students to incorporate knowledge from a variety of backgrounds and apply a breadth of information. While it is recognized that critical thinking is important for student success in professional school and future careers, a specific strategy to tackle a novel problem is lacking in student training. We have developed a four-step systematic approach to solving case studies that improves student confidence and provides them with a definitive road map that is useful when solving any novel problem, both in and out of the classroom. This approach encourages students to define unfamiliar terms, create a timeline, describe the systems involved, and identify any unique features. This method allows students to solve complex problems by organizing and applying information in a logical progression. We have incorporated case studies in anatomy and neuroanatomy courses and are confident that this systematic approach will translate well to courses in various scientific disciplines.

[8] This chapter is a slightly modified version of *A Systematic Approach to Solving Novel Problems Improves Critical Thinking Skills* published in *Journal of Microbiology & Biology Education* and has been reproduced here with the permission of the copyright holder.
[9] Reference: Meyer C, Hall H, Heise N, Ivie KR, Clapp TR. A systematic approach to solving novel problems improves critical thinking skills. *JMBE*. 2018; *19*(3).
[10] Link: https://www.asmscience.org/content/journal/jmbe/10.1128/jmbe.v19i3.1593
[11] I was involved in the research design, IRB approval, and data collection.

5.2. INTRODUCTION

There is increasing emphasis in pedagogical research on encouraging critical thinking in the classroom. The specific mental processes and behaviors involved require the individual to engage in reflective and purposeful thinking. Critical thinking encompasses the ability to examine ideas, make decisions, and solve problems [1-2]. The skills necessary to think critically are essential for learners to evaluate multiple perspectives and solve novel problems in the classroom and throughout life. Career success in the 21st century requires a complex set of workforce skills. Current labor market assessments indicate that by the year 2020, the majority of occupations will require workers to display cognitive skills such as active listening, critical thinking, and decision making [3-4]. In particular, current studies show that the US economy is impacted by a deficit of skilled workers able to solve problems and transfer learning to any unique situation [3].

The critical thinking skills necessary to tackle novel problems can best be addressed in higher education institutions [5-6]. Throughout education, and specifically in college courses, students tend to be required to regurgitate knowledge through a myriad of multiple-choice exams. Breaking this habit and incorporating critical thinking can be difficult for students. While the ability to recite information is helpful for establishing base knowledge, it does not prepare students to tackle novel problems. Ideally, the objective of any course is to encourage students to move beyond recognition of knowledge into its application [7]. Considering this, the importance of critical thinking is widely accepted; however, there has been some debate in educational re- search regarding how to teach these skills [8]. Research has demonstrated that students show significant improvements in critical thinking as a result of explicit methods of instruction in related skills [9-10]. Explicit instruction provides a protocol on how to approach a problem. By establishing the necessary framework to work through unfamiliar details, we enable students to independently solve complex problems.

These skills, which are important in every facet of the workforce, are vital for students in the sciences [10-11]. Here, we discuss a specific process that teaches students a systematic approach to solving case studies in the anatomical sciences. Case studies are a popular method to encourage critical thinking and engage students in the learning process [12]. While the examples described here are specifically designed to be implemented in anatomy and neuroanatomy courses, this platform lends itself to teaching critical thinking skills across scientific disciplines. This four-step approach encourages students to work through four separate facets of a problem:

- *Define unfamiliar terms*
- *Create a timeline associated with the problem*
- Describe the (anatomical) *systems involved*
- *Identify any unique features associated with the case*

Often, students start by trying to plug in memorized facts to answer a complicated question quickly. With the four-step approach, students learn that before “solving” the case study, they must analyze the information presented in the case. The case studies implemented are anatomically- based case studies that emphasize important structural relationships. The case may include terminology with which the students are not familiar. They therefore begin by identifying and defining unfamiliar terms. They then specify the timeline in which the problem occurred. Establishing a timeline and narrowing the focus can be critical when considering the relevant pathology. Students must then describe the anatomical systems involved (e.g., musculoskeletal or circulatory), and finally list any additional unique features of the case (e.g., lateral leg was struck, or patient could not abduct the right eye). By dissecting the details along the lines of these four categories, students create a clear roadmap to approach the problem. Case studies with a clinical focus are complex and can be overwhelming for unpracticed students. However, teaching students to follow this systematic approach gives them the tools to begin to carefully dismantle even the most convoluted problem.

5.2.1. Intended Audience

This approach to solving case studies has been applied in undergraduate courses, specifically in the sciences. This curriculum is currently utilized in both human gross anatomy and functional neuroanatomy capstone courses. While it is ideal to implement this process in a course that runs in parallel with a lecture-heavy course, it can also be utilized with case studies in a typical lecture class.

Anatomy-based case studies lend themselves well to this problem-solving approach due to the complexities of clinical problems. However, we believe with an appropriately designed case study, this model of teaching critical thinking can easily be expanded to any discipline. This activity encourages critical thinking and engages students in the learning process, which we believe will better prepare them for professional school and careers in the sciences.

5.2.2. Prerequisite Student Knowledge

Required previous student knowledge only extends to that which students learn through the related course taken previously or concurrently. Application of this approach in different classroom settings only requires that students have a basic understanding of the material needed to solve the case study. As such, the case study problem and questions should be built around current topics being studied in the classroom.

Using unfamiliar words teaches students to identify important information. This encourages integration of information and terminology, which can be critical for understanding anatomy. Simple terms, like superficial or deep, guide discussions about anatomical relationships. While students may be able to recite the definitions of these concepts, applying that information to a case study requires integrating the basic definition with an understanding of the relevant anatomy. Specific prerequisite knowledge for the sample case study is detailed in Appendix 1.

5.2.3. Learning Time

This process needs to be learned and practiced over the course of a semester to ensure long-term retention. With structured and guided attempts, students will be able to implement this approach to solving case studies in one 50-minute class period (Table 5.1). The course described in this study is a capstone course that meets once weekly. Each 50-minute class period centers around working through a case study. As some class sessions are reserved for other activities, students complete approximately 10 case studies during the semester. Students begin to show increased confidence with this method within a few weeks and ultimately are able to integrate this approach into their critical thinking skillset by the end of the semester. Presentation of the case study, individual or small group work, and class discussion are all achieved in one standard class session (Table 5.1). The current model does not require student work prior to the class meeting. However, because this course is taken concurrently with a related, content-heavy lecture component, students are expected to be up to date on relevant material. Presenting the case study in class to their peers encourages students to work through the systematic approach we de- scribe here. Each case study is designed to correlate with current topics from the lecture-based course. Following the class period, students are expected to complete a written summary of the discussed case study. The written summary should include a detailed explanation of the approach they utilized to solve the problem, as well as a definitive solution. Written summaries are to be completed two days after the original class period.

Table 5.1 Anticipated In-Class Time to Implement this Model

Activity	Approximate Time Anticipated
Presentation of the case study	5 minutes
Individual or small group work	15 minutes
Class discussion	30 minutes

5.2.4. Learning Objectives

This model for teaching a systematic approach to solving case studies provides a framework to teach students how to think critically and how to become engaged learners when given a novel problem. By mastering this technique, students will be able to:

1. Recognize words and concepts that need to be defined before solving a novel problem.
2. Recall, interpret, and apply previous knowledge as it relates to larger anatomical concepts.
3. Construct questions that guide them through which systems are affected, the timeline of the pathologies, and what is unique about the case.
4. Formulate and justify a hypothesis both verbally and in writing.

5.3. PROCEDURE

As a faculty member, it can be challenging to create ap- propriate case studies when developing this model for use in a specific classroom. There are resources that provide case studies and examples that can be tailored to specific classroom needs. The National Center for Case Study Teaching in Science (University at Buffalo) can be a useful tool. The ultimate goal of this model is to teach an approach to problem solving, and a properly designed case study is crucial to success. To build an effective case study, faculty must include sufficient information to provide students with enough base knowledge to begin to tackle the problem. This model is ideal in a course that pairs with a lecture-heavy component, utilized in either a supplementary course or during a recitation. The case study should be complex and not quickly solved. An example of a simplified case study utilized in Human Gross Anatomy is detailed in Appendix 1.

This particular case study encourages students to think through the anatomy of the lateral knee, relevant structures in this area, and which muscle compartments may be affected based on movement disabilities within the case. While more complex case studies can certainly be developed for the Neuroanatomy course through Clinical Case Studies, this case study provides a good example of a problem to which students cannot immediately provide the answer. They must think critically through the four-step process to identify the "diagnosis" for this patient.

5.3.1. Materials

This approach to solving case studies can be integrated into the classroom with no special materials. However, we use a PowerPoint presentation and personal whiteboards (2.5' x 2') to both improve delivery of the case study and facilitate small group discussion, respectively. The Power- Point presentation is utilized by faculty to assist in leading the classroom discussion, prompting student responses and projecting relevant images. As the faculty member is presenting the case study during the first five minutes of class (Table 5.1), the wording of the case study can be displayed on the PowerPoint slide as a reference while students take notes.

5.3.2. Faculty Instructions

It is helpful to first present an overview of the approach and to solve a case study together as a class. We recommend giving students a lecture describing the benefits of a systematic approach to case studies and emphasizing the four-step approach outlined in this paper. Following this lecture, it is imperative that faculty walk the students through the first case study. This helps to familiarize students with the approach and lays out expectations on how to break down the individual components of the case. During the initial case study, faculty must heavily moderate the discussion, leading students through each step of the approach using the provided Case Study Handout (Appendix 2). In subsequent weeks, students can be expected to show increasing independence.

Following initial presentation of the case study in class, students begin work that is largely independent or done in small groups. This discussion has no grades assigned. How- ever, following the in-class discussion and small group work, students are asked to detail their approach to solving the case study and their efforts are graded according to a set rubric (Appendix 3). This written report should document each step of their thought process and detail the questions they asked to reach the final answer, providing students with a chance for continual self-evaluation on their mastery of the method.

Implementing this model in the classroom should focus not only on the individual student approach, but also on creating an encouraging classroom environment and promoting student participation. Student questions may prompt other student questions, leading to an engaging discussion-based presentation of the case study, which is crucial to increasing confidence among students, as has been seen with the data represented in this paper. When moderating the discussion, it is important that faculty emphasize to students that the most critical goal of the exercise is to learn how to ask the next most appropriate question. The questions should begin with broad concepts and evolve to discussing specific details. Efforts to quickly arrive at the answer should be discouraged.

Students should be randomly assigned to groups of two to three individuals as faculty members moderate small group discussion during class. Randomly assigning students to different groups each week encourages interaction be- tween all students in the class and promotes a collaborative environment. Within their small groups, students should work through the systematic four-step process for solving a novel problem. Students are not assigned specific roles within the group. However, all group members are expected to contribute equally. During this process, it can be beneficial to provide students with a template to follow (Appendix 2). This template guides their discussion and encourages them to use the four-step process. Additionally, each small group is given a white board that they can use to facilitate their small group discussions. Specifically, asking students to write down details of each of the four facets of the problem (definitions, timeline, systems involved, unique features) and how they arrived at these encourages them to commit to their answers. This also ensures they have concrete evidence to support their "diagnosis" and that they have confidence in presenting it to the class. Two or three small groups are chosen randomly each week to present their hypothesis to the class using their whiteboard.

5.3.3. Suggestions for Determining Student Learning

The cadence of the in-class discussion can provide an informal gauge of how students are progressing with their ability to apply the systematic approach. The discussion for the initial case studies should be largely faculty led. Then, as the semester progresses, faculty should step back into a facilitator role, allowing the dialogue to be carried by the students.

Additionally, requiring students to write a detailed summary of their approach to the problem provides a strong measure of student learning. While it is important for students to document their final "diagnosis" or solution to the problem, the focus of this assignment is primarily on the process and the series of relevant questions the student used to arrive at the answer. These assignments are graded according to a set rubric (Appendix 3).

5.3.4. Sample data

The following excerpt is from a student who showed marked improvement over the course of the semester in implementing this approach to solving case studies. The initial submission for the case study write-up was rudimentary, did not document the thought process through appropriate questions, and lacked an in-depth explanation to demonstrate any critical thinking. By the end of the semester, this student documented a logical thought progression through this four-step approach to solving the case study. This student, additionally, detailed the questions that led each stage of critical thinking until a "diagnosis" was reached (complete sample data are available in Appendix 4).

> *Initial sample:* "Given loss of sensory and motor input to left lower limb, right anterior cerebral artery ischemia caused the sensory and motor cortices of the contralateral (left) lower limb to be without blood flow for a short amount of time (last night). The lack of flow led to a fast onset of motor and sensory paresis to limb."

> *Final sample:* "...the left vestibular nuclei which explains the nystagmus, and the left cerebellar peduncles which carry information that aids in coordinating intention movements. My next question was where in the brainstem are all of these components located together? I narrowed this to the left caudal pons. Finally, I asked which artery supplies the area that was damaged by the lesion? This would be the left anterior inferior cerebellar artery."

5.3.5. Safety issues

There are no known safety issues associated with implementing this approach to solving case studies.

5.4. DISCUSSION

The primary goal of the model discussed here is to give students a method that uses critical reasoning and helps them incorporate facts into a complete story to solve case studies. We believe that this model addresses the need for teaching the specific skill set necessary to develop critical thinking and engage students in the learning process. By encouraging critical thinking, we begin to redirect the tendency to simply recite a memorized answer. This four-step approach to solving case studies is ideal for the college classroom, as it is easily implemented, requires minimal resources, and is simple enough that students demonstrate mastery within one semester. While it was designed to be used in anatomy and neuroanatomy courses, this platform can be used across scientific disciplines. Outside of the classroom, in professional school and future careers, this approach can help students to break down the details, ask appropriate questions, and ultimately solve any complex, novel problem.

5.4.1. Field testing

This model has been implemented in several courses in both undergraduate and graduate settings. The data and approach detailed here are specific to an undergraduate senior capstone course with approximately 25 students. The lecture-based course, which is required to be taken concurrently or as a prerequisite, provides a strong base of information from which faculty can develop complex case studies.

5.4.2. Evidence of Student Learning

Student performance on written case study summaries improved over approximately ten weeks of practicing the systematic four-step approach (Figure 5.1). As indicated by the data, scores improve and begin to plateau around five weeks, indicating a mastery of the approach. In the spring 2016 semester, a marked drop in scores was observed at week 8. We believe that this reflects a particularly difficult case study that was assigned that week. After observing the overall trend in scores, instructional format was adjusted to provide students with more guidance as they worked through this particular case study.

After the class session, students were asked to provide a written summary of their findings. A set rubric (Appendix 3) was used to assess students on their ability to apply basic anatomical knowledge as it relates to the timeline, systems involved, and what is unique in each case study. Students were also asked to describe the questions that they had asked in order to reach a diagnosis for the case study. The questions formulated by students indicate their ability to bring together previous knowledge to larger anatomical concepts. In this written summary, students were also required to justify the answer they arrived at in each step of the process. In addition to these four steps, students were assessed on the organization of their paper and whether their diagnosis is well supported.

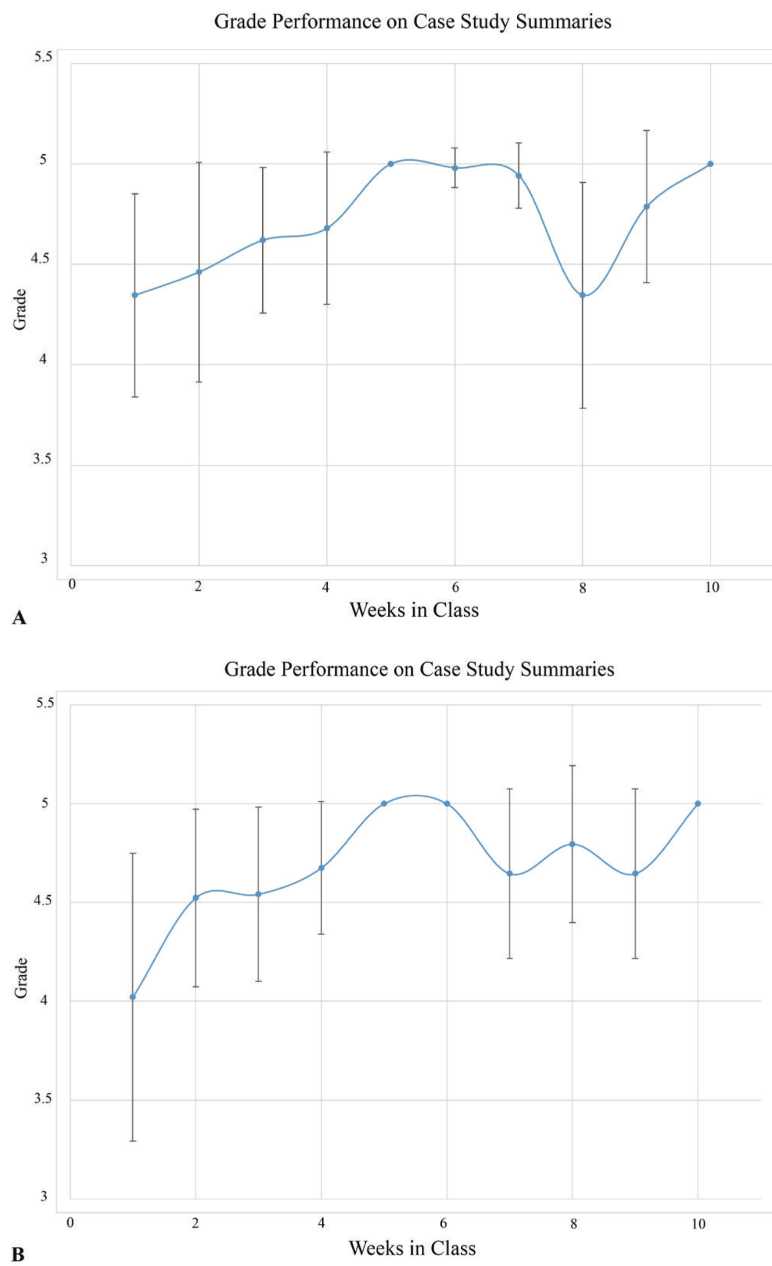

Figure 5.1 Grade Performance in Case Study Written Summaries as Measured with the Grading Rubric Throughout the Semester

A) Mean (with SD) grade performance in case study write-ups in the spring semester of 2016. B) Mean (with SD) grade performance in case study write-ups in the spring semester of 2017. Overall grade performance in case study written summaries improved through- out the 10 weeks in which this method was implemented in the classroom. Written summaries are graded based on a set rubric (Appendix 3) that assigned a score between 0 and 1 for five different categories. Data represent the mean of students' scores and the associated standard deviation. Improved student performance throughout the semester indicates progress in successful incorporation of this method to solve a complex novel problem.

Although class participation was not formally assessed, the improvements demonstrated in the written assignments were mirrored in student discussions in the classroom. While it is difficult to accurately assess how well students think critically, students demonstrated success in learning this module, which provides the necessary framework for approaching and solving a novel problem.

5.4.3. Student Perceptions

Students were asked to answer the open response question, "Describe the process you use to figure out a novel problem or case study." Responses were anonymized, then coded based on frequency of responses. Responses were collected at the start of the semester, prior to any instruction in the described systematic approach, and again at the end of the semester (Figure. 5.2 and 5.3). Overall, student comments indicated that mastering this four-step approach greatly increased their confidence in tackling a novel problem. Below are some sample student responses.

"Rather than being intimidated with a set of symptoms I can't explain, I'm now able to break them down into simpler questions that will lead me down a path of understanding and accurate explanation."

> "I now know how to address an exam question or life problem by considering what is needed to solve it. This knowledge will help me to address each problem efficiently and calmly. As a future nurse, I will benefit from developing a logical and stereotypical approach to solving problems. I have learned to assess my thinking and questioning and modify my approach to problem-solving. While the problems may be different in the future, I am confident that I will be able to efficiently learn from my successes and setbacks and continually improve."

"I'm sure I'll use this approach when I'm faced with any other novel problem, whether it's scientific or not. Stepping back and establishing what I know and what I need to find out makes difficult problems a lot more approachable."

> "Before, I would look at all the information presented and try to find things that I recognized. Then I would simply ask myself if I knew the answer. Even if I did actually know the answer, I had no formula to make the information understandable, cohesive, or approachable. I now feel far more confident when dealing with novel problems and do not become immediately overwhelmed."

This approach encourages students to quickly sort through a large amount of information and think critically. Although students can find the novel nature of this method cumbersome in the initial implementation in the classroom, once they become familiar with the approach, it provides a valuable platform for attacking any novel problem in the future. The ability to apply this approach to critical thinking in any discipline was also demonstrated, as is evidenced by the two following student responses:

> "When I first thought about this question and when solving case studies, I tried to find the answer immediately. I'm good at memorizing information and spitting it back out but not working through an issue and having a method. I definitely have a more successful way to think through complex problems and being patient and coming up with an answer."

"I already use it in many of my other classes and life cases. When I take an exam that is asking a complicated question or is in a long format, I work to break it down like I did in this class and try to find the base question and what the answer may be. It has actually helped significantly."

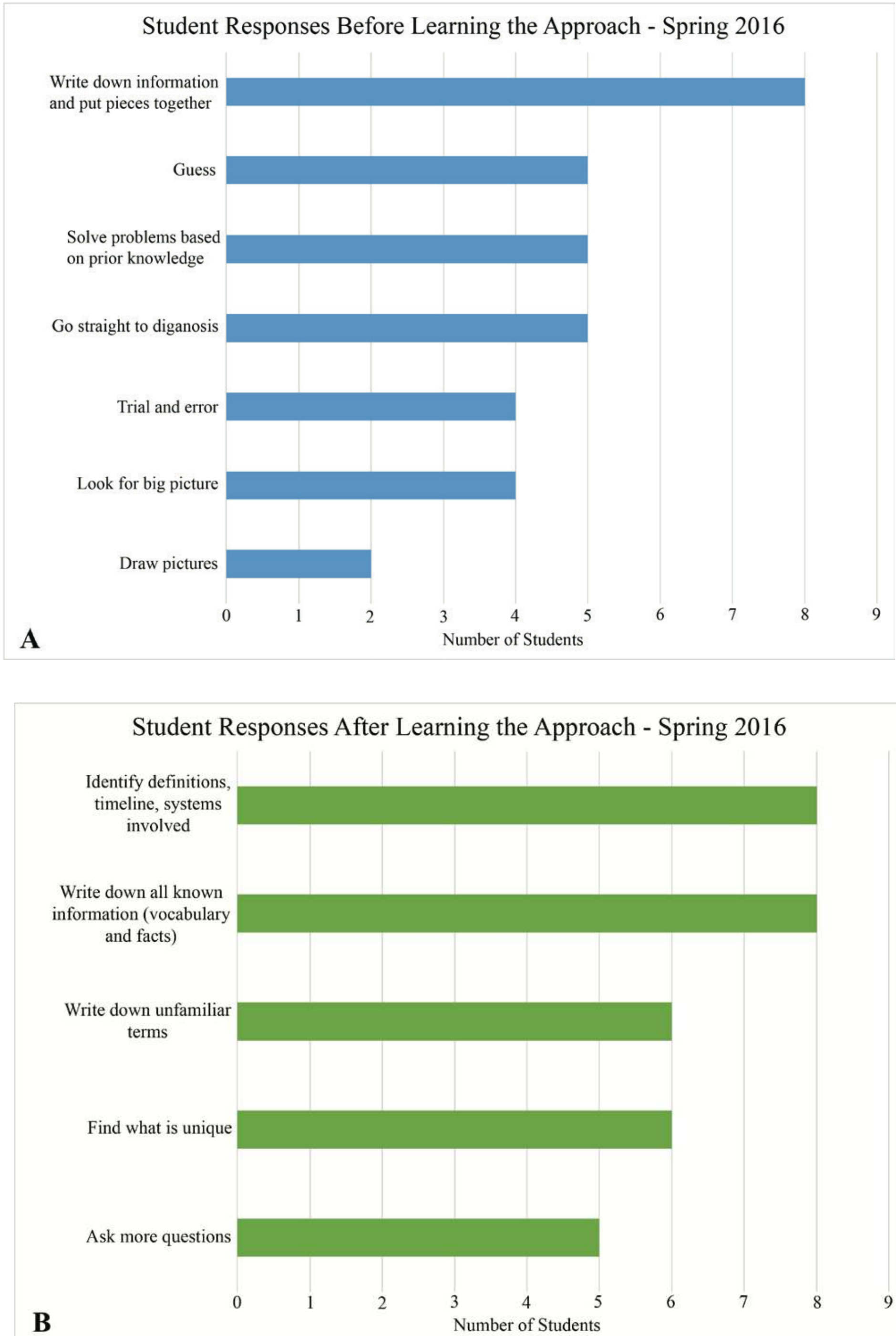

Figure 5.2 Student Responses to a Survey Regarding Their Approach to Solving a Novel Problem

Data were collected prior to and following the completion of the spring semester of 2016. A) Student approach to solving a novel problem at the beginning of the semester. B) Student approach to solving a novel problem at the end of the semester. Student responses indicate that following a semester of training in using this method, students prefer to use this four-step systematic approach to solve a novel problem.

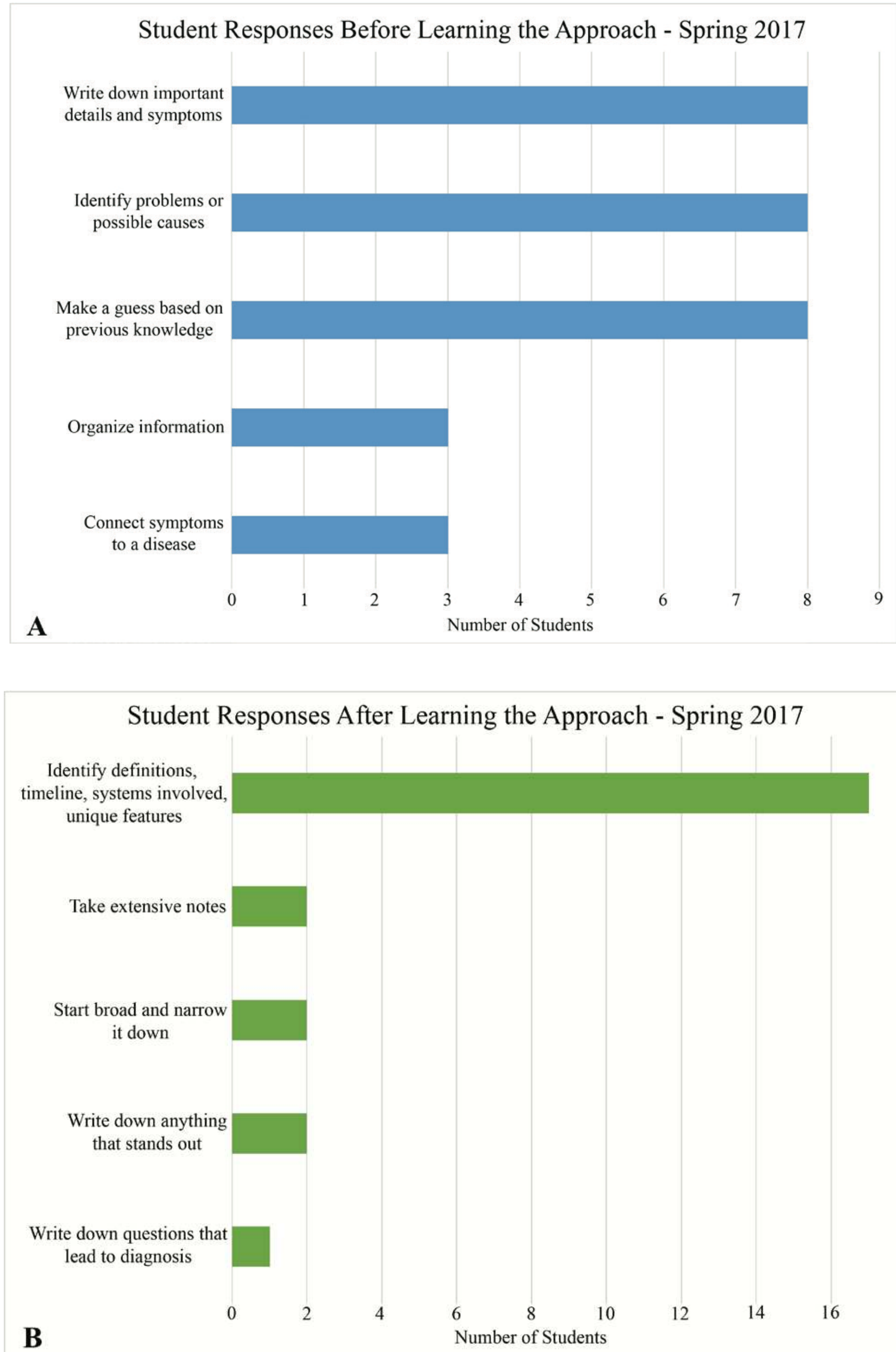

Figure 5.3 Student Responses to a Survey Regarding Their Approach to Solving a Novel Problem

Data were collected prior to and following the completion of spring semester of 2017. A) Student approach to solving a novel problem at the beginning of the semester. B) Student approach to solving a novel problem at the end of the semester. Student responses indicate that students overwhelmingly utilize this systematic approach when solving a novel problem.

5.4.4. Possible Modifications

Currently, students are randomly assigned to groups each week. In future semesters, we could improve small group work by utilizing software that helps to identify individual student strengths and assign groups accordingly. Additionally, while students are given flexibility within their small groups, if groups struggle with equality of workload, we could assign specific roles and tasks. We are also using this model in a large class (100 students) and assessing understanding of the case study through instant student response questions (ICLICKER). While this model does not allow for the valuable in-depth classroom discussions, it still presents the approach to students and allows them to begin to implement it in solving complex problems. Preliminary data from these large classes indicate that students initially find the method difficult and cumber- some. Further development and testing of this model in a large classroom will improve its use for future semesters.

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CHAPTER VI – HYDROCEPHALUS[12][13]

The following is a teacher manual on how to implement case-based learning and the four-step systematic approach into the scientific classroom.

6.1. CASE STUDY

Background

An 18-month-old child is brought to her pediatrician for a routine check-up. Her father explains that she has been showing signs of a painful headache for several weeks now, which is causing significant pain. In addition, she appears very lethargic on some days and mentation seems slower than usual. The patient's head appears to be enlarged and is not proportional to her face and body.

Physical Examination

Patient is conscious and is afebrile. An MRI reveals heavily dilated lateral, third and fourth ventricles, in addition to a swollen subarachnoid space surrounding the brain. A visual examination reveals bilateral mildly blurred vision and papilledema. A spinal tap reveals elevated intracranial pressure.

Questions

1. Describe the ventricular system of the brain, including the location of each ventricle and the structures that connect them. What is the purpose of these spaces?
2. Describe cerebrospinal fluid (CSF) in terms of overall function, production and reabsorption.

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[12] This chapter is a slightly modified version of *Hydrocephalus* ready for submission to *National Center for Case Study Teaching.*
[13] List of authors: Natascha Heise, Katelyn Brown, Tod R. Clapp

3. Based on the symptoms presented, is the patient suffering from communicating or noncommunicating hydrocephalus? How do you know?
4. The vast majority of hydrocephalus cases are the result of a blockage between ventricles, as opposed to a tumor or blockage within an individual ventricle. How can you explain this?

6.2. TEACHING NOTES

6.2.1. Introduction and Background

The attached case study features a patient with hydrocephalus, a condition in which an increased volume of cerebrospinal fluid (CSF) is located in the ventricles and or the subarachnoid space. It can be caused by a blockage of circulation (most common), decreased reabsorption at the arachnoid granulation (not common), or an increased production of CSF (i.e., choroid papilloma, rarely). A variety of therapeutics have been developed to manage symptoms and remove excess fluid.

This case study is a modified example of the case studies used in a graduate human anatomy class offered at Colorado State University. This one-credit course consists of one 50-minute weekly meeting for 16 weeks, in which a different case is presented each week. Throughout the semester, students are required to use a stereotypical approach to analyze these novel problems, improving their critical thinking skills. These sessions are held in a discussion-based seminar style. On average, 20 students are enrolled each year who have either taken an undergraduate human anatomy class or are concurrently enrolled.

Critical thinking is important for learner success in professional schools and future careers, however, providing specific strategies to tackle novel problems is lacking in student preparation. For that reason, we have developed a four-step systematic approach to solving case studies that improves student confidence, social engagement, and provides them with a definitive road map when solving novel problems.

6.2.1.1. Approach

Our approach consists of the following components:

- Definition
- Timeline
- Systems involved
- What is unique
- Broad questions

This method allows students to solve complex problems by organizing and applying information in a logical progression. We have incorporated this approach in human anatomy and neuroanatomy courses, and we are confident that this systematic approach will translate well to courses beyond scientific disciplines, as it changes the way students approach a problem. Rather than getting lost in the details, students start with the bigger picture by identifying and gathering important information before analyzing details.

6.2.1.2. Objectives

Upon completion of this case students should be able to:

- Describe the ventricular system of the brain, including the location of the ventricles and the structures that connect them.
- List the functions of cerebrospinal fluid (CSF).
- Explain the difference between the production and reabsorption of CSF.
- Describe the difference between a communicating or noncommunicating hydrocephalus.
- Discuss different clinical representations of hydrocephalus cases and their causes.

There are several objectives for this case beyond teaching the anatomy of the ventricular system:

- Help students use a structured approach to solving novel problems.
- Reinforce the collaborate nature of this approach.

- Give students the opportunity to apply their anatomical knowledge and relate it to case scenarios.

6.2.2. Classroom Management

We have run this case according to a modified version of the problem-based learning method; students are given the case at the beginning of a class period, then use our systematic approach to get an overview of the case and identify the broad nature of the problem. During class, they define all important case terms to obtain a firm starting point. The students are then divided in groups and search for the answers of the case. Outside of class, student groups meet up, discuss and resolve problems that were identified earlier. Lastly, students are required to submit a written case analysis, demonstrating a thorough understanding of the underlying anatomy, pathology, and problem-solving approach. The following discussion is divided into the section "Preliminary" (i.e., preparation before class), "Case Session" (i.e., in class structure), and "Assessment" (i.e., homework with submission of group answers).

6.2.2.1. Preliminary

Before starting the case, students are expected to have an understanding of the background details of the ventricular system of the brain as well as the production and reabsorption of CSF. In our classroom setting, students have covered this content in a lecture format in a prerequisite undergraduate human anatomy class or are concurrently enrolled. Review of the material prior to the case does not take place during class time. Supplemental learning materials includes the Atlas of Human Anatomy by Frank H. Netter and the Neuroanatomy Atlas by Duane E. Haines.

6.2.2.2. Case Session

The individual case discussion sessions last 50 minutes. The instructor spends 2-3 minutes introducing the four-step approach, which is projected on a screen (definitions, timeline, systems involved, unique features, broad questions). This systematic approach utilizing case studies provides the learners with a framework when solving novel problems linked to real-world contexts. It also helps them to organize their thoughts and start broad when trying to determine a diagnosis.

Following this introduction, the instructor projects the written case (Background and Physical Examination) and reads it out loud. Students take detailed notes on the case as the instructor reads. The fast-paced reading from the instructor is important in order to let the students practice concise notetaking; students do not have the time to write down every detail or read the screen, so they must learn to identify the important information presented. Once completed, the instructor turns off the screen and students start working in their respective groups of four for approximately ten minutes. During this time, students focus on using the systematic approach.

A student-driven discussion follows, beginning with students asking for specific terms they would like defined. Importantly, students are encouraged to ask for definitions on both unfamiliar words (i.e., papilledema), and any important terms they might overestimate their understanding of (i.e., meninges). Once defined by the instructor, a discussion of the correct timeline, systems involved and what is unique follows. Students tend to put different aspects into the unique category and there is no right or wrong answer here as long as students can justify their selection. Since the students have prepared notes for this discussion, every student can individually be addressed here.

The majority of time should be spent on determining the broadest question and applying their anatomical knowledge to the case. After ten minutes at most of prior discussion, the biggest broadest questions are determined and answered by the students with the help of the instructor. From there, more detailed questions are asked until a diagnosis is reached. At the end of the class session, the four additional case study questions are displayed on the projector and given as a group homework assignment. The focus of the class session is not to always come up with a diagnosis but rather engage and help the students in using their anatomical knowledge and the systematic approach. If the instructor has to sacrifice time for more discussion, groups of students are required to do some research on their own for their homework assignment.

6.2.2.3. Assessment

After class, groups of students are required to get together and work on answering the additional case study questions collaboratively. A discussion of the approach and all answers to the additional questions are submitted by each group, including citations utilized within one week of the case presentation (a few days before the next class). The grading rubric used to assess student performance is available for student reference and can be found at the end of the case answer key (Table 6.1). Our students complete their assignment via an online learning management system and graduate teaching assistants grade all submissions on a weekly basis.

6.2.2.4. Problems

Instructors have faced problems when students are not engaged in the case or have not reviewed the material prior to attending class. We helped them in using cases that have just recently been covered in the lecture component of the undergraduate human anatomy class. The maximum of students enrolled in the class was set to around 20 students to increase student interaction but still give each student the opportunity to voice their thought process. Graduate Teaching Assistants had to be trained on giving detailed feedback. Feedback mostly consists of filling knowledge gaps in their write-ups. The training helped the students to use their feedback more efficiently and apply it to the next week's case write-up.

It was also necessary to constantly remind the students that the diagnosis is not what we wanted them to get out of each case. In the beginning of the semester, students focused on detail instead of looking at the big picture. Class discussions in approaching each case first with broad questions helped them to fully understand and utilize the systematic approach. Additionally, the rubric got modified in order to draw students' attention to use the approach correctly rather than having them state the correct diagnosis.

6.2.3. Blocks of Analysis

Students must be introduced to the following topics prior to solving the case.

6.2.3.1. Cranial Meninges

There are three connective tissue layers surrounding the central nervous system (CNS) that are important for protection in suspending the nervous tissue, decreasing movement of the brain, and housing CSF. The innermost meningeal layer, pia mater, is closest to the nervous tissue and composed of fine collagenous and elastic fibers. The second layer, arachnoid, is composed of collagen and elastin as well as fibroblasts. Between the two layers is a space called the subarachnoid space in which CSF accumulates. Expanded regions of the subarachnoid space are referred to as cisterns. Firmly attached to the arachnoid is the dura mater which is the outermost layer connected to the skull. It is thick, collagenous, and forms venous dural reflections that form blood filled spaces called dural sinuses that are important for the venous drainage of the blood in the brain.

6.2.3.2. Ventricular System in the Brain

There are four ventricles in the brain that are continuous with the central canal of the spinal cord and the subarachnoid space. They are fluid filled and a remnant of the embryonic canal. These ventricles provide a space for CSF production and accumulation. Two lateral ventricles, bounded laterally by the caudate nucleus, are separated on midline by the septum pellucidum. The 3^{rd} ventricle is laterally bordered by the thalamus and connected with the lateral ventricles by the interventricular foramen. The 4^{th} ventricle is connected with third ventricle by the mesencephalic aqueduct and located posterior to the brainstem and anterior to the cerebellum. The 4^{th} ventricle also has an opening into the subarachnoid space through one median and two lateral recesses. Each ventricle is lined with a choroid epithelium, capillaries, and a small amount of connective tissue. The choroid epithelium creates cerebrospinal fluid.

6.2.3.3. CSF Production and Reabsorption

The functions of the CSF are to protect the brain, increase buoyance, maintain ECF environment, and transport some hypothalamic hormones. It can be found in the ventricular system of the brain and in the subarachnoid space. The majority is produced by active secretion by the choroid plexus found in the ventricular system of the brain which is not influenced by blood pressure or pressure of CSF within the ventricles. First, filtered plasma moves from fenestrated capillaries in the choroid plexus into an interstitial space. Since the choroid plexus contains tight junctions between cells, substances do not freely move into CSF and only certain ions and gases can move across this barrier. Sodium, potassium, and chloride are actively secreted into the ventricular lumen which creates osmotic pressure to draw water into the CSF via aquaporins. This fluid then circulates through the ventricles and central canal. It will get into the subarachnoid space via lateral and median apertures that are located at the 4th ventricle. The cranial subarachnoid space is continuous with the subarachnoid space in the spinal cord and thus contains the same CSF that can be found within the skull. CSF returns to the vascular system via arachnoid granulations which are tufts of arachnoid that protrude through the dura into the dural venous sinuses. These are one-way valves and work pressure-dependently in a passive process. The venous sinuses around the brain drain eventually into the internal jugular vein returning the blood to the heart. Generally, around 150 ml of CSF accumulates within the CNS with a turnover rate of three to four times a day.

6.3. CASE ANSWER KEY

6.3.1. Preparation for Case Discussion in Class

The case discussion mainly focuses on using the systematic approach and using the broadest questions to guide the students to the diagnosis.

Definitions:

- Headache = pain in any region of the head

- Lethargic = lack of energy; sluggish and apathetic
- Mentation = mental activity
- Conscious = aware of and responding to one's surroundings; awake
- Afebrile = not feverish
- MRI = short for magnetic resonance imaging; used to record brain activity
- Blurred vision = lack of sharpness of vision resulting in the inability to see fine detail
- Papilledema = swelling of the optic nerve
- Spinal tap = lumbar puncture
- Intracranial pressure = pressure exerted by fluid such as CSF inside the skull and on the brain tissue; measured in millimeters of mercury (mmHg)

Timeline: The timeline for this case is slow (acute) as symptoms have progressed over several weeks.

Systems involved:

- The nervous system is involved due to the slow mentation and specifically the somatosensory system due to the pain and headaches.
- The integumentary system is involved due to the enlarged head.
- The visual system is involved due to the impaired vision and papilledema.

What is unique: Unique for this case are the enlarged head, the impaired vision and papilledema as well as the elevated intracranial pressure.

Broadest questions:

- What are the cranial ventricles?
- Where are the ventricles located?

- What is the fluid circulating in the brain and around the spinal cord?
- What are the cranial meninges?
- How is CSF produced?
- How is CSF reabsorbed?
- What is the flow of CSF?
- What is the pathway for vision?
- What could cause blurred vision?
- Why did the pediatrician perform a spinal tap?

Diagnosis: This patient suffered from a communicating type of hydrocephalus. This may have been the result of a congenital or acquired disease shortly after birth that impaired the reabsorption of CSF at the arachnoid granulations. The vision is impaired as the increased intracranial pressure exerts a force onto the optic nerve.

6.3.2. Assessment

Following are the answers to the additional questions of the case.

A. *Describe the ventricular system of the brain, including the location of each ventricle and the structures that connect them. What is the purpose of these spaces?*

There are four ventricles in the brain that are continuous with the central canal of the spinal cord and the subarachnoid space. They are fluid filled and a remnant of the embryonic canal. These ventricles provide a space for CSF production and accumulation. Two lateral ventricles, bounded laterally by the caudate nucleus, are separated on midline by the septum pellucidum. The 3rd ventricle is laterally bordered by the thalamus and connected with the lateral ventricles by the interventricular foramen. The 4th ventricle is connected with third ventricle by the mesencephalic aqueduct and located posterior to the brainstem and anterior to the cerebellum. The 4th ventricle also has an opening into the subarachnoid space through one median and two lateral recesses. Each ventricle is lined with a choroid epithelium, capillaries, and a small amount of connective tissue. The choroid epithelium creates cerebrospinal fluid.

B. *Describe cerebrospinal fluid (CSF) in terms of overall function, production and reabsorption.*

The functions of the CSF are to protect the brain, increase buoyance, maintain ECF environment, and transport some hypothalamic hormones. It can be found in the ventricular system of the brain and in the subarachnoid space. The majority is produced by active secretion by the choroid plexus found in the ventricular system of the brain which is not influenced by blood pressure or pressure of CSF within the ventricles. First, filtered plasma moves from fenestrated capillaries in the choroid plexus into an interstitial space. Since the choroid plexus contains tight junctions between cells, substances do not freely move into CSF and only certain ions and gases can move across this barrier. Sodium, potassium, and chloride are actively secreted into the ventricular lumen which creates osmotic pressure to draw water into the CSF via aquaporins. This fluid then circulates through the ventricles and central canal. It will get into the subarachnoid space via lateral and median apertures that are located at the 4^{th} ventricle. The cranial subarachnoid space is continuous with the subarachnoid space in the spinal cord and thus contains the same CSF that can be found within the skull. CSF returns to the vascular system via arachnoid granulations which are tufts of arachnoid that protrude through the dura into the dural venous sinuses. These are one-way valves and work pressure-dependently in a passive process. The venous sinuses around the brain drain eventually into the internal jugular vein returning the blood to the heart. Generally, around 150 ml of CSF accumulates within the CNS with a turnover rate of three to four times a day.

C. *Based on the symptoms presented, is the patient suffering from communicating or noncommunicating hydrocephalus? How do you know?*

Based on the symptoms presented, the patient is suffering from a communicating hydrocephalus. In this type, CSF can still flow between the ventricles. This is shown by the enlarged lateral, third and fourth ventricles as well as the subarachnoid space. CSF is produced in all ventricles but flows from the lateral ventricles to the third ventricle via the interventricular foramen. From there, it flows through the mesencephalic aqueduct to the fourth ventricle and exits the ventricular system via the lateral and median recesses. It circulates within the subarachnoid space before it gets reabsorbed into the venous system. This patient may have suffered from a congenital or acquired hydrocephalus shortly after birth that caused an impairment in the reabsorption of CSF at the arachnoid granulations. A non-communicating hydrocephalus, also called "obstructive hydrocephalus", occurs when the flow of CSF is blocked. Blockages can generally be found in one of the narrow passages connecting the ventricles.

D. *The vast majority of hydrocephalus cases are the result of a blockage between ventricles, as opposed to a tumor or blockage within an individual ventricle. How can you explain this?*

The passages connecting the ventricles are very narrow and thus prone to occlude rather than occluding an entire ventricle. Some people are born with even narrower passageways that restrict the flow of CSF but may not show any symptoms until later.

Table 6.1 Rubric for Case Reports

	Excellent (1 pt)	Average (0.5 pts)	Needs Improvement (0 pts)
Definitions	A list of terms found in or relevant to the case is present with comprehensive definitions in the student's own words. These terms are integrated appropriately into the differential diagnosis.	A list of terms found in or relevant to the case is present with incomplete definitions. It is not clear the student understands all the definitions, some are defined incorrectly. These terms are integrated appropriately into the differential diagnosis.	Few terms found in or relevant to the case are present with incomplete/incorrect definitions. These terms are poorly integrated and/or used in the differential diagnosis.
Timeline	Timeline is accurate. Explanation of how this refines the focus is clear. Timeline is integrated appropriately into the differential diagnosis.	Timeline is inaccurate or missing. No explanation of relevance. **OR** No integration into differential diagnosis.	Timeline is inaccurate or missing. No explanation of relevance. **AND** No integration into differential diagnosis.
Systems Involved	Student has named systems involved, including which are intact, which are damaged. Systems are appropriately integrated including laterality in the differential diagnosis.	Student has named systems involved, including which are intact, which are damaged. Systems are not appropriately integrated **OR** laterality is inaccurate in the differential diagnosis.	Student has not included appropriate systems Systems are not integrated **AND** laterality is inaccurate in the differential diagnosis.
Unique Features	Some unique aspects of the case are documented. When appropriate these are accurately explained in the differential diagnosis	Some unique aspects of the case are documented. Those that are applicable are not accurately explained in the differential diagnosis	No documentation of anything unique.
Questions Organization Diagnosis	The write-up has clear organization by topic sentence, body, and conclusion. ***Questions are appropriate, relevant, and have clearly guided the student through the case. The most appropriate recorded questions are recorded and speculated.*** Diagnosis is well supported and has a clear explanation of ***why*** it was chosen.	The write-up has some poor organization by topic sentence, body, and conclusion. ***Questions are recorded and somewhat appropriate. The recorded questions occasionally help with working through the case.*** Diagnosis is partially supported and has a rough explanation of ***why*** it was chosen.	The write-up is poorly written with no organization by topic sentence, body, and conclusion. ***Recorded questions are not appropriate and do not help work through the case.*** Diagnosis has no support and is not clearly understood.

CHAPTER VII – ENGAGING HIGH SCHOOL STUDENTS IN A UNIVERSITY-LED SUMMER ANATOMY CAMP TO PROMOTE STEM MAJORS AND CAREERS[14][15][16]

7.1. SUMMARY

University-led K-12 outreach programs are designed to expose students to a variety of fields and career choices, but the benefits and outcomes of these have not been well documented. Existing programs often range from short presentations to more extensive residential summer programs. Nationally, there are only a few university-led high school human anatomy camps, with no current publications focusing on a formal evaluation of their goals. Described herein is a week-long human anatomy summer camp at Colorado State University (CSU) designed to inspire high school students to attend college and attract them to STEM majors and careers. The camp schedule includes lectures presented by CSU's faculty, hands-on activities including learn from human cadavers and animal organs, as well as mentorship opportunities. Success of the program is measured by qualitative feedback and a follow-up survey to measure if the goals of the camp were well received. The data shows that all 28 of the senior high school students who attended camp have applied to college and are considering a STEM career after college. Camp counselors have reported continued mentor/mentee relationships with the students after camp.

7.2. INTRODUCTION

Many public and charter schools lack formal hands-on science laboratories which could be largely be attributed to the decrease in funding for Science, Technology, Engineering, and Mathematic (STEM)

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[14] This chapter is a slightly modified version of *Engaging High School Students in a University-Led Summer Anatomy Camp to Promote STEM Majors and Careers* published in *Journal of STEM Outreach.*

[15] Reference: Heise N**,** Hall HA, Ivie KR, Meyer CA, Clapp TR. Engaging high school students in a university-led summer anatomy camp to promote STEM majors and careers. *Journal of STEM Outreach*. 2020; 3(1).

[16] Link: https://www.jstemoutreach.org/article/18374-engaging-high-school-students-in-a-university-led-summer-anatomy-camp-to-promote-stem-majors-and-careers

programs [1-2]. Additionally, there is an increased curricular focus on standardized testing, which ultimately decreases students' opportunities to explore all aspects of STEM, including exposure to college majors and career choices [3-4]. In a recent study, high school and college students expressed that the most important factor influencing their career choice is the information provided by teachers, school counselors, and their parents [5]. Information regarding STEM college majors and career choices is limited to the knowledge of faculty and staff, and by the funding and resources available to each school. In order to increase college enrollments in STEM majors, extracurricular outreach activities are needed to give students access to more information regarding their choices in college and beyond. Universities are in a unique position to facilitate this endeavor by widening students' interest in STEM through valuable experiences on a college campus where resources and expertise are abundant. Following is a description of re- ported summer camps focusing on engaging and recruiting high school students into STEM.

At the University of Rhode Island Kingston campus, Levine and colleagues created a weeklong chemistry camp for middle school students filled with hands-on experiments, field trips, and interaction with female scientists [6]. One key goal of camp was to encourage the girls' interest in STEM disciplines and STEM careers. Survey results showed success in changing attitudes towards applicability of science and interest in pursuing a STEM-related career. Similarly, Adventures in Chemistry Camp is a week-long program during which students lived in college residence halls at the University of Nebraska Kearney and participated in daily hands-on chemistry experiments [7]. The intent was to facilitate their first college experience. The small faculty-to-student ratio and the open-ended laboratory projects conducted in a research setting were important components of this camp compared to other chemistry camps currently offered. Results indicated that overall, the camp was well perceived by the students. In their exit survey, students indicated that they enjoyed staying in the dorms and conducting research with their advisor.

To increase interest and knowledge about STEM, Hammack and colleagues [4] measured the effects of a week- long engineering summer camp on middle school students. School teachers and one engineering professor from a local university facilitated the camp at their school and measured how participating in a weeklong engineering summer camp affected middle school students' attitudes towards engineering. Findings indicated that the students improved their understanding of technology and attitudes towards engineering. Likewise, Yilmaz and colleagues [8] created a camp called YESTexas (Young Engineers of South Texas) with the goal to expose high school students to STEM concepts through a set of hands-on engineering projects. Results demonstrated that 24 out of 30 (80%) of the high school students had an increased interest in engineering disciplines after attending camp. Overall, the camp provided an opportunity to promote critical thinking, teamwork, writing, and leadership skills.

"Girls on the Go: The Mobile Computing College Experience" is a summer camp designed for high school girls [9]. This camp was created to encourage the students to attend college and to interest them in computer science as a possible career option. This camp was free of charge, held at Miami University in Florida, and focused on technical, informational, and social activities to give the students an idea of a balanced college experience. A comparison of pre- and post-surveys on 28 students suggested that the girls' confidence in computer science and their understanding of careers in computer science increased. Furthermore, ten out of 25 students volunteered to continue working on the design for a computer application started during camp. In addition to laying a foundation of STEM knowledge and experience, residential camps create mentorship opportunities. University mentors provide more information about college majors, share their college experiences, and offer encouragement [10]. Mentors have an opportunity to shift student perception of social norms regarding choices regarding college majors and activities.

It is not uncommon for first-year college students to struggle with a sense of belonging, which could be addressed by having mentors present on campus before or during their Freshman year [11-12]. In 2014, Castleman created a peer-mentor intervention through which college students and advisors conducted outreach to support high school graduates in their college transition [10]. Text and peer mentor interactions composed of in-person meetings and follow-up phone conversations took place in urban school districts in Boston, Lawrence, and Springfield (MA), Dallas (TX), and Philadelphia (PA). College enrollment varied across study sites ranging from 14 to 53% [10]. Castleman proposed that this method provided a "low-cost behavioral nudge" helping students reduce the complexity associated with navigating college and financial aid information. It also increased parents' awareness of required pre-matriculation tasks. However, these interventions were only designed to help with applying to college and did not include continuous mentorship.

To date, only a few university-led summer high school camps focusing on human anatomy have been documented, such as the Clinical Anatomy Summer Program at Stanford [13], the One-Week Summer Medicine Program at Boston Leadership Institute [14], and the Anatomy & Physiology Camp at the Appalachian State University Beaver College of Health Sciences [15]. All of the aforementioned programs focus on using hands-on anatomy exercises to expose students to a variety of career options. However, there is a lack of a detailed evaluation of the goals and outcomes of these camps. The field would benefit from more research on how to successfully implement and assess the impact of these outreach endeavors. To simultaneously address the issues of exposing students to a variety of career options within STEM, especially the medical field, facilitate their first college experience, and create a long-term mentor- ship program, we developed a week-long human anatomy camp for high school students at Colorado State University.

7.3. METHODS

The main goals of the camp were to (1) expose high school students to various activities involving anatomy and introduce them to a variety of STEM major and career options, especially within the medical field, (2) facilitate their first college experience and (3) enable mentorships. Reported herein is the development, implementation, and evaluation of this summer anatomy camp, as well as implications for future outreach efforts (Figure 7.1).

7.3.1. Camp Application and Student Cohort

Colorado State University's annual Anatomy Camp was launched in summer of 2016 and takes place at the Fort Collins campus. High school students are accepted to camp based on several factors including year in school, interest in science, leadership potential, and written essay responses. Students need to have completed two years of high school to be eligible to apply. Applications are accepted until camp is full; once camp is full; applications are accepted for the waitlist. Tuition for anatomy camp is $1,850 per student and includes six nights of lodging in a residence hall, meals, a laboratory manual written by CSU's Biomedical Sciences faculty, supplies, extracurricular camp activities, and a set of scrubs. Three scholarships are available to campers seeking financial support: The diversity scholarship aims to recognize and support students with diverse cultural, socioeconomic and ethnic backgrounds. The overcoming adversity scholarship provides support for students that have demonstrated strength in the face of adversity. Finally, the leadership award recognizes incoming campers that display leadership qualities and is funded by donations from previous camp counselors, faculty and parents of former campers.

Figure 7.1 Photographs of Camp Activities

Clockwise from top left: Whitewater rafting; suture clinic; clay modeling; laboratory work; case study work; VR exposure; laboratory work; visit at the local museum.

As the camp is residential, applications are collected from all over the country with the greatest number of applicants from Colorado, followed by California. In addition to traditional camp registration forms, parents of attendees are required to send complete consent forms, either agreeing or declining their child's ability and desire to take part in this research study. Campers are also asked to describe, in essay form, their expectations and hesitations about camp. Each year, 32-34 students are accepted, split into six total groups with two assigned counselors who help guide them through- out the week.

Counselors are a mix of both graduate and undergraduate students who have successfully completed the human anatomy courses at CSU (Human Gross Anatomy, Honors Gross Anatomy, Human Anatomy Dissection, and Advanced Human Anatomy). Counselors undergo a rigorous application process which includes submitting resumes, essays describing mentoring experiences, and references. Applicants are then brought in for a group interview where they need to demonstrate teamwork, leadership ability, compassion for others, and problem solving.

In the weeks preceding camp, selected counselors participate in an online course designed to introduce them to concepts of teaching and learning. Topics include educational philosophy, experiential learning and multiple intelligences, ice breakers, Bloom's taxonomy, lesson planning, and critical thinking. Two in-person training days are also scheduled to further work on these topics and receive feedback from faculty and staff on their lessons. After camp, the counselors are required to reflect and submit an essay on their experiences. Their impressions are collected not only to improve camp, but also to provide an opportunity for personal reflection.

All high school campers stay in a residence hall to facilitate a real campus experience. The counselors have individual rooms distributed along the hall of the dorm to facilitate interactions between counselors and students. This arrangement enhances our goal of enabling mentorship opportunities. Comparing the accepted high school students over the years of 2017-2019 ($n = 100$), it can be observed that 83% of high school camp attendees identified as female and 17% as male. The female to male ratio for counselors is generally about the same every year (Table 7.1).

Table 7.1 Overview of Accepted High School Students

	2017	2018	2019
Total number of students	34	34	32
Number of females	29	28	26
Number of males	5	6	6
Number of camp counselors	10	10	10

Total number of students, number of females and males, and number of camp counselors during camp in 2017, 2018, and 2019.

7.3.2. Camp Curriculum

The camp schedule builds off two main goals to expose high school students to a college-level anatomy experience and to a variety of STEM major and career options. Table 7.2 illustrates this schedule with human anatomy lectures, computer-based cross-sectional anatomy, and solving clinical case studies. Faculty and staff from the Department of Biomedical Sciences facilitate the daily lectures and laboratories, which are designed to mimic the undergraduate anatomy course. The lecture and laboratory content allow each camper to experience a college level course. This experience is a valuable experiential learning tool as well as an effective college recruitment tool.

In order to make college-level content accessible to high school students, each counselor facilitates a hands-on, inter- active lesson at the beginning of each day. Counselors have reported that this teaching experience is incredibly valuable for their personal and professional growth. Additionally, it exposes the campers to the material in a fun, low-pressure environment. This gives campers confidence with the new material before they step foot into a more fast-paced faculty-led lecture.

Each camp day incorporates significant time learning from prosected human cadavers and dissecting animal organs in the laboratory. These laboratory sessions provide students with hands-on experiences from human cadavers in a small group setting. The regions covered throughout camp are organized chronologically as follows: Lower Limb; Thorax, Abdomen and Pelvis; Head and Neck; and Upper Limb. Laboratory sessions are accompanied by a written guide authored by CSU's faculty and staff to provide students a more self-directed learning experience. When the students are in the laboratory, they are divided into their respective groups and assigned to one cadaver at a time. For 15-20 minutes, the students focus only on one system (blood supply, nerves, bones, musculoskeletal, radiographs) within a specific region of anatomy. During that time, they use the provided laboratory guide as a written narrative that leads them on a self-guided discovery of each system. After 20 minutes, the groups rotate to another cadaver to learn about a different system. Counselors and faculty are present at each station to guide them and answer any questions. At the end of the week, counselors and faculty facilitate a fun anatomy challenge in which students compete to test their acquired anatomy knowledge. Similar to a laboratory examination in the human anatomy course at CSU, campers are exposed to a tagged cadaver. In their respective groups and with a provided word bank, campers try to associate the tagged structure with the correct anatomical term. The group with the highest number of correct answers wins a prize.

At CSU, we are fortunate to have both Animal Anatomy and Human Anatomy laboratories. This provides us with the unique opportunity to offer an interactive comparative laboratory lesson to increase the application of knowledge. During this hour, students are exposed to a variety of animal specimens to compare specific anatomical features across species. Many high school students are still narrowing down their interests and we believe that providing them with more options within biomedical sciences is valuable.

To be successful in the discipline of anatomy, it is important to be able to understand spatial and structural relationships [16]. Many students, even at the professional level, struggle with analyzing two-dimensional images. To introduce this concept, we incorporated digital cross-sectional anatomy exercises in each anatomical region throughout the week. Software programs including the Visible Human Dissector [17] and CSU's own virtual reality program (BananaVision) expose students to two-dimensional cross-sections and link these to complete three-dimensional anatomy. We believe this early introduction to cross-sectional study gives students a glimpse of the anatomy seen in medical imaging.

Anatomy Camp's curriculum is based around six clinical case studies chosen to highlight different regions of the body. In order to solve the case studies, campers learn a four-step systematic approach to help them solve the novel problem. This method has been previously described by Meyer and colleagues [18]. After the students have read the clinical case, they are encouraged to ask for definitions on unfamiliar terms, determine the correct timeline of symptoms (chronic or acute), explain what systems could be involved (musculoskeletal, nervous, integumentary etc.), and state what other unique features are in the case study. Once these fundamental questions are answered, students identify the major concern of the patient and apply their anatomical knowledge until a diagnosis is reached. During the week of camp, each group of students is required to work through the systematic approach with their assigned clinical case study. Counselors provide guidance but encourage small groups to research the case on their own. Each group is assigned a different case that focuses on an important anatomical concept. All lectures and laboratories are designed to help campers solve their case. Each team then creates a presentation covering the anatomy of their case study. This activity enhances their critical thinking and presentation skills. It also provides each student the opportunity to work collaboratively within their group. During the final day of camp, each small group presents their case study findings in front of faculty, peers, and families. Practicing this approach provides students with a framework that can be applied to any novel problem. This technique can be a valuable tool throughout their academic career.

To supplement the academic aspects of camp, campers are given free time in the residence hall, campus tours, and time to explore CSU's recreational center. Campers and counselors are also given the opportunities to experience the surrounding area with outings at the Fort Collins Museum of Discovery, a whitewater rafting trip in the Poudre Canyon, and a group hike at Horsetooth Mountain Park. While campers and counselors naturally develop a mentor/mentee relationship, these fun activities away from the classroom provide additional opportunities for the counselors to share their college experiences. Mentors often share their favorite courses exposing high school students to the variety of STEM material offered at CSU. In addition, the college's Assistant Director of Student Success meets with the campers over lunch and shares information about the college and undergraduate degrees. To increase their exposure to the STEM field in the greater Fort Collins community, we invite a medical professional from the surrounding community to talk about pathways into medicine. This interaction exposes the students to careers they may not have even known existed in the medical field.

Table 7.2 Overview of Camp Activities

ANATOMY CAMP
DEPARTMENT OF BIOMEDICAL SCIENCES

Anatomy Camp Weekly Schedule

	SUNDAY	MONDAY	TUESDAY	WEDNESDAY	THURSDAY	FRIDAY	SATURDAY
Time							
7:00-7:45AM		Breakfast	Breakfast	Breakfast	Breakfast	Breakfast	Breakfast
8:00 AM		Counselor Lesson #1	Counselor Lesson #2	Counselor Lesson #3	Counselor Lesson #4	Counselor Lesson #5	Pack and Clean-up Rooms
9:00 AM	*Camp Staff Arrive*	Welcome and Expectations	Lower Limb Case Study	Hike to Horsetooth	Upper Limb Lab	Upper Limb Case Study	Final Reflections
10:00 AM	Counselors Check in to Dorms	Introduction to Case Studies	TAP Cross Section			Upper Limb Cross Section	Present Case Study / Camp Video
11:00 AM	Counselor Lunch	Lunch	TAP Lecture	Box Lunch @ Horsetooth	Upper Limb Lecture	CSU Bookstore	
12:00 PM	Set up for Arrival	Case Studies	Lunch	*Free/Shower/Change*	Lunch	Lunch	*Campers Depart*
1:00 PM	Campers Arrival/Unpack		TAP Case Study	Head/Neck Cross Section	Change, get ready for rafting	Anatomy Challenge	Counselor Clean up and Reflection
2:00 PM	Games	Lower Limb Lecture	Case Studies	Head/Neck Lecture	White Water Rafting	Sheep Brain	
3:00 PM	Group Welcome	Lower Limb Lab	Pig Heart Dissection and TAP Lab	Head/Neck Lab		Comparative/Animal Anatomy Lab	
4:00 PM	Selfie Tour					Museum of Discovery	*Camp Staff Departs*
5:00 PM	Cookout for Dinner	Dinner	Dinner	Dinner		Ice Cream in Old	
6:00 PM	Suture Clinic	*Paths into Medicine with guest speaker B110*	*Rec Center/Outside*	Suture clinic	Dinner	Picnic Dinner	
7:00 PM	Movie Night - Dorm	Blood pressure lab			*Free/Shower/Change*	Practice Case Studies on campus	
8:00 PM		*Free/Shower/Change*	*Free/Shower/Change*	Work on Case Studies	Work on Case Studies	Practice Case Studies on campus	
9:00 PM	Free time in Dorm	Free time in Dorm	Free time in Dorm	Free time in Dorm	Free time in Dorm	Finalize Case Studies	
10:00 PM	Counselor Meeting/In Rooms	Counselor Meeting/In Rooms	Counselor Meeting/In Rooms	Counselor Meeting/In Rooms	Counselor Meeting/In Rooms	Counselor Meeting/In Rooms	
11:00 PM	Lights Out	Lights Out	Lights Out	Lights Out	Lights Out	In Rooms/Lights Out	

7.4. EVALUATION

In order to evaluate the impact of CSU's Anatomy Camp on high school seniors attending camp in 2017, 2018 and 2019, a full board review was approved by CSU's Institutional Review Board (19-9636H). The Anatomy Camp team collected observations and feedback during and at the end of camp. Additionally, a formal follow-up survey facilitated through SurveyMonkey was sent out to all senior students approximately one year after their attendance:

- Why did you sign up for camp?
- What major are you considering in college?
- Did CSU's Anatomy Camp change your perception about STEM majors in college? Explain why.
- What do you want to do as a career after college?

The response rate of the follow-up survey in 2017 was 83.3%, 66.7% in 2018, and 85.7% in 2019 (Table 7.3), with all three years averaging 78.6%. Among the respondents, 25 of the 28 high school students (89.3%) indicated that they attended camp because they wanted to go, two (7.1%) stated that their parents encouraged them to attend, and one student (3.6%) reported that they signed up for camp to attend with their friends (Figure 7.2).

Table 7.3 Follow-up Survey Responses

	2017	**2018**	**2019**
Number of contacted students	12	9	14
Responses	10	6	12
No Responses	2	3	2
Response Rate	83.3%	66.7%	85.7%

Number of contacted students for the follow-up survey in 2017, 2018, and 2019 with their responses, no responses, and response rate.

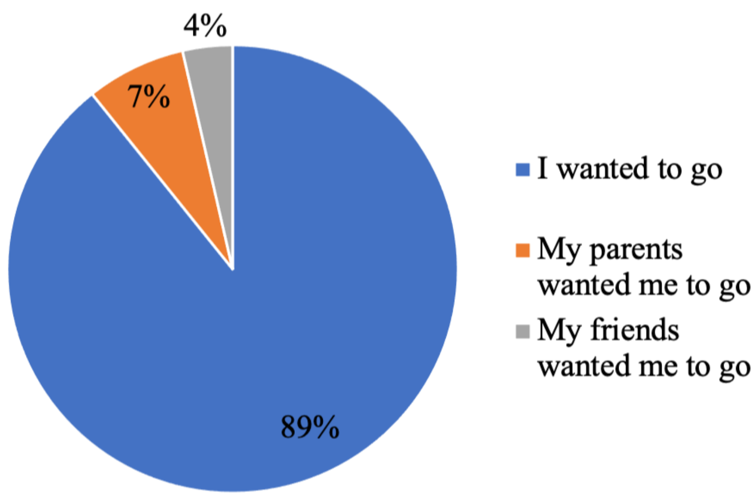

Figure 7.2 Reasons for Signing Up for Camp

Students had to indicate their reason why they signed up for Anatomy Camp (n = 28).

Overall, the camp was well received by the high school students, parents, and the undergraduate and graduate students who served as camp counselors. High school students reported that they mostly enjoyed the cadaver laboratories and suture clinics as they mimicked working in a health profession. Furthermore, they appreciated working with counselors of different majors, meeting a medical guest speaker, and talking to the college's Assistant Director of Student Success about admissions.

The first goal of camp was to expose high school students to various activities involving anatomy and showing them a variety of STEM majors and career options. Data show eleven students (39.3%) were considering Biomedical Sciences/Microbiology/Environmental Health/Neuroscience as a major in college, eight students (28.6%) were considering a Biology/Zoology/Botany major, three (10.7%) were looking into Chemistry/Biochemistry, and two (7.1%) were interested in Psychology/Human Development. Additionally, four (14.3%) selected "Other" as an answer choice and were considering Epidemiology, Speech disorders, Anthropology, or a mix of Psychology and Neuroscience. The answer choices "Engineering/Mathematics/Physics, Nursing", and "not attending college" weren't selected (Figure 7.3).

Importantly, 14 students (50%) indicated that CSU's anatomy camp changed their perception and opinions about STEM majors in college. Qualitative data from the high school students specified that "Camp showed [them] that a STEM major is possible and even fun;" that "it made [STEM] less intimidating," that "females can do it," and "it showed [them] how expansive the medical field really was, other than becoming a physician." Based on the survey responses, it was unclear why the 14 other students (50%) selected that there was no change in perception of STEM majors in college. It may be that these students likely were already interested in STEM before attending camp. Lastly, 22 students (78.6%) respond- ed that they intended to pursue a career as a professional in the medical field including as a physician, a veterinarian, physician assistant, nurse, dentist, physical therapist, or veterinary technician. Two students (7.1%) indicated that they would like to pursue research in the medical field, one student (3.6%) was interested in the biotechnology industry, and one (3.6%) would like to pursue a career in forensics. Two students (7.1%) were unsure about their future (Figure 7.4).

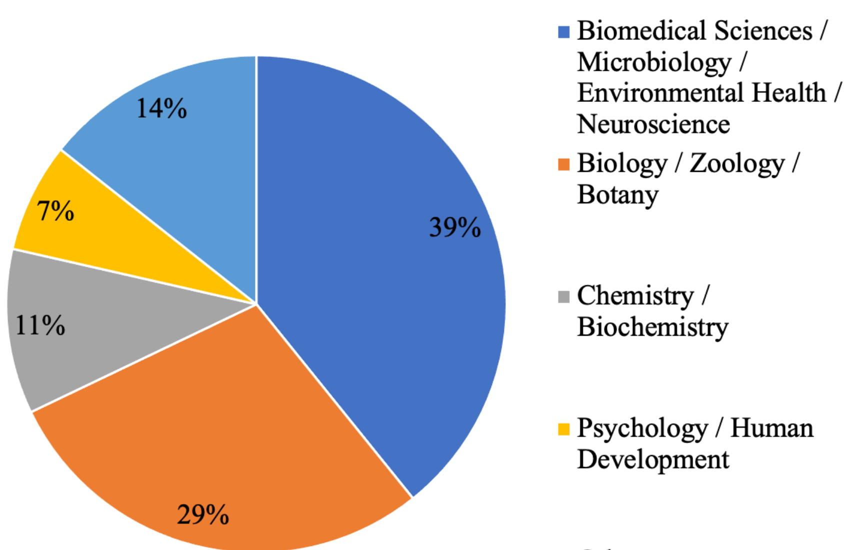

Figure 7.3 Consideration of Major in College

Students had to indicate what major they are considering in college (n = 28).

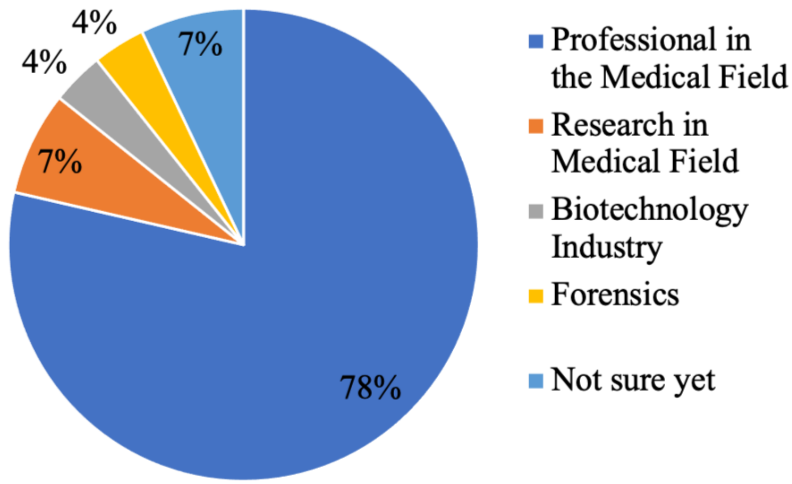

Figure 7.4 Career Aspirations

Students had to choose of a variety of career options they would like to pursue in the future (n = 28).

The second goal of camp was to facilitate the students' first college experience. Staying in the dorms for the duration of the camp was an adjustment for some students. However, observations throughout the week indicated that the overnight stay enabled students to quickly form friendships and get acclimated to CSU's campus. Students reported that it showed them a glimpse of life as a college freshman, living and dining in a college dorm.

The third goal of camp was to enable mentorships. Email addresses between counselors and students were exchanged at the end of camp. Counselors have reported that students have reached out for advice with their college application which further underlines the impact of counselors through- out the camp experience.

7.5. CONCLUSION

After four successful years of implementation of Anatomy Camp at CSU, the immersive college experience has provided unique opportunities for many high school students. This opportunity simulates a college experience, complete with campus living for the duration of the camp and the delivery of educational content from faculty. Campers participate in various activities involving human anatomy laboratories, including learning from prosected human cadavers and solving complex clinical case studies. Student campers are exposed to STEM majors and career options within the medical field through interactions with faculty, staff, and student counselors. The follow-up survey indicated that all 28 of the senior high school students who attended Anatomy Camp have applied to college and are currently considering a STEM career after college. Furthermore, camp counselors reported continued mentee/mentor relationships with the students after camp and have helped them with their college applications.

Limitations of this study include lack of a follow-up survey for non-senior students. In the future, a survey will be sent out to the students who attended camp as a junior and are considering college following their high school graduation. It would be interesting to explore in future studies whether the effects observed in the follow-up survey responses will persist over multiple years. Future efforts will focus on continuing to administer surveys to students who attended camp, to track their long-term interest in science, as well as their choice of future career after college. Additionally, there is a lack of a formal survey for the camp counselors in order to assess their experiences as well as their impact on the high school students. Data on their mentoring experiences will be collected and evaluated in order to enhance the study. Lastly, including international students would add a unique cultural diversity that would improve the camp experience for all campers and counselors. Enhanced recruitment for Anatomy Camp at CSU may be used to attract international students in the future.

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CHAPTER VIII – SUMMARY AND CONCLUSION

The goal of Chapters II through VII was to evaluate existing techniques in the human anatomy and neuroanatomy classroom at Colorado State University (CSU), purposefully implement new teaching methods, and make recommendations for educators of the anatomical sciences and other disciplines. A mixed methods approach was used in all studies to take student perceptions of integrated and multimodal teaching paradigms into account in addition to student outcomes. This methodology shed light on the benefits and implications of the different pedagogical implementation techniques.

The studies described in Chapter II reviewed the value of low-stakes frequent quizzing in a cadaveric laboratory. The aim of this study was to investigate the relationship between weekly table quizzes and the overall student outcomes in a graduate biomedical human dissection class as well as to examine the benefits and implications of this approach. The data suggested a potential correlation between performance on weekly quizzes and on unit examinations. This uniquely structured assessment tool provided the students with the opportunity to practice the retrieval of their knowledge, feel more guided throughout their dissection, and receive immediate feedback on their performance. It further provided a way to predict student outcomes and an opportunity for early intervention to help at-risk students. As many medical schools and other health-related institutions have moved away from lecture-based methods, these low-stakes quizzes will enable educators and learners to use the time in the cadaveric laboratory more efficiently.

Chapter III investigated the role of technology in anatomy education, specifically examining learner engagement and retention when utilizing Virtual Reality (VR). A large-scale virtual reality undergraduate course was coordinated and deployed to supplement online human anatomy instruction. The program enabled students to work collaboratively in a common virtual space and learn human anatomy on an artist-rendered cadaver. Results suggested that using VR was comparable to two-dimensional methods in student knowledge acquisition and retention of anatomical relationships. Qualitative data collection indicated that

VR promoted student engagement and increased opportunities for students to interact with teaching assistants, peers, and the content as a whole. 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. Distance education has increased in popularity as it accommodates learners who are non-traditional, from rural communities, or otherwise require a greater degree of flexibility in coursework modalities. This course may provide a highly engaging and interactive solution to distance education in various disciplines.

The purpose of the studies in Chapter IV was to investigate how a semester-long group project in a cadaveric graduate classroom at CSU and Rocky Vista University affected students' group dynamic, personal development, experience, and learning approach. Twenty interviews were conducted, and a case study analysis with thematic analysis were performed in conjunction with Forsyth's conceptual framework on group dynamics. Results indicated that the majority of participants were pleased with their group members but preferred not to study or spend their free time together. 85% of students stated that they underwent a change in their development as a group member and have modified their learning strategies from rote memorization to being able to connect the material as a whole. Overall, students appreciated a smaller student-to-cadaver ratio, as it provided more time to dissect and greater opportunities to engage with the material. Dissecting in larger groups at RVU, however, may be more beneficial when students face a large workload outside of the dissection course or when they are not planning on using their dissection skills in the future. This study may have generated findings critical for the understanding of how group work in the cadaveric laboratory can affect students in their learning and personal development, in addition to their knowledge acquisition. Educators teaching in any group-setting should consider these effects to evaluate which group size will generate the desired results for their corresponding curriculum.

The use of case studies in an undergraduate classroom was investigated in Chapter V. CSU has developed and implemented a four-step systematic approach to solving case studies with the hope to improve student confidence and provide them with a definitive useful road map when solving any novel problem. This approach encouraged students in the neuroanatomy classroom to define unfamiliar terms, create a timeline, describe the systems involved, and identify any unique features. Results indicated that student performance on written case study summaries improved over approximately ten weeks of practicing the systematic four-step approach. Further, students reported that the approach greatly increased their confidence in tackling a novel problem. Since case studies have widely been used in the scientific classroom, this systematic approach will translate well to courses in various disciplines helping students organize and apply information in a logical progression. In addition, Chapter VI provides a teacher's manual explaining the detailed use and application of the approach in the classroom while using the neurological condition hydrocephalus as an example.

Chapter VII focuses on the design, implementation, and evaluation of a full-time, week-long human anatomy camp at CSU. This camp was designed to expose high school students to a variety of STEM career options (especially within the medial field), facilitate their first college experience, and create a long-term mentorship program. Undergraduate and graduate mentors worked closely with students on case studies to help students apply their anatomical knowledge and develop critical thinking and presentation skills. Success of the program was measured by a follow-up survey one-year after camp, indicating that all 28 senior high school students had applied to college and were considering STEM as a career path. Camp counselors have further reported continued mentor/mentee relationships with the students after camp. Recruiting students into STEM through small outreach events has been well documented, however, these endeavors are limited and include mostly one-day activities and are located within the respective middle or high school facilitated by their teachers. The study described in Chapter VII is the first attempt to evaluate the effects of such an outreach endeavor that can be used as a guide for other summer camps. It further evaluates the use of case studies in the classroom and as a way to work and connect high school with college students.

Overall, these studies address effectiveness of anatomy education at the undergraduate and graduate level through in-person, remote, and outreach instructional methods. The use of a mixed method approach increases the significance and power of the discussed findings, as this approach takes unique insight from student and faculty experiences into account in addition to quantitatively assessed student outcomes. The findings in this body of works suggest that anatomy education should include problem-based learning methods that focus on the development of critical thinking skills and ability to apply knowledge to a novel problem. Additionally, frequent low-stakes quizzes, long-term group work, and technology have the potential to promote student engagement and outcomes. These studies recommend consistent evaluation of existing teaching methods through the lens of evidence-based learning theories to continually improve student learning experience and mastery of anatomical content. This evaluation will inform educators in the anatomical sciences and other disciplines on practical methods to supplement or substitute existing teaching practices, promoting a shift to more effective and active learning in the time restricted classroom.

APPENDIX

A. APPENDIX 1 – SAMPLE CASE STUDY

A 28-year-old professional hockey player was struck in the lateral leg slightly inferior to his right knee with a puck during a game. After leaving the ice and removing his skates, the player noticed he was unable to lift the toes on his right foot. He also had to lift his right leg higher than his left when he walked, as his toes would drag along the floor if he didn't. He also noticed a slight weakness in plantar flexion in the right limb and numbness in the dorsum of the right foot.

Prerequisite knowledge: For this particular case study, students require prerequisite knowledge of the layout of the nerves in the lower limb, the innervation of the muscle compartments in the leg, and the specific actions of the muscles in the leg.

B. APPENDIX 2 – CASE STUDY HANDOUT

Key points to remember:

- These should help you think critically about the anatomy
- What are the most appropriate and broad questions?
- Please use the systematic approach outlined below!
- At the end, you will write a summary of your approach to solving this case study.

First, write down key facts and concepts from the case study:

-
-
-

Define the following in your small groups:

Definitions:
Timeline (acute or chronic?):
Systems involved (right or left side?):
Unique features:

- What additional questions need to be answered?

C. APPENDIX 3 – CASE STUDY GRADING RUBRIC

	Excellent (1 pt)	Average (0.5 pts)	Needs Improvement (0 pts)
Definitions	A list of terms found in or relevant to the case is present with comprehensive definitions in the student's own words. These terms are integrated appropriately into the differential diagnosis.	A list of terms found in or relevant to the case is present with incomplete definitions. It is not clear the student understands all the definitions, some are defined incorrectly. These terms are integrated appropriately into the differential diagnosis.	Few terms found in or relevant to the case are present with incomplete/incorrect definitions. These terms are poorly integrated and/or used in the differential diagnosis.
Timeline	Timeline is accurate. Explanation of how this refines the focus is clear. Timeline is integrated appropriately into the differential diagnosis.	Timeline is inaccurate or missing. No explanation of relevance. **OR** No integration into differential diagnosis.	Timeline is inaccurate or missing. No explanation of relevance. **AND** No integration into differential diagnosis.
Systems Involved	Student has named systems involved, including which are intact, which are damaged. Systems are appropriately integrated including laterality in the differential diagnosis.	Student has named systems involved, including which are intact, which are damaged. Systems are not appropriately integrated **OR** laterality is inaccurate in the differential diagnosis.	Student has not included appropriate systems Systems are not integrated **AND** laterality is inaccurate in the differential diagnosis.
Unique Features	Some unique aspects of the case are documented. When appropriate these are accurately explained in the differential diagnosis	Some unique aspects of the case are documented. Those that are applicable are not accurately explained in the differential diagnosis	No documentation of anything unique.
Questions Organization Diagnosis	The write-up has clear organization by topic sentence, body, and conclusion. ***Questions are appropriate, relevant, and have clearly guided the student through the case. The most appropriate recorded questions are recorded and speculated.*** Diagnosis is well supported and has a clear explanation of ***why*** it was chosen.	The write-up has some poor organization by topic sentence, body, and conclusion. ***Questions are recorded and somewhat appropriate. The recorded questions occasionally help with working through the case.*** Diagnosis is partially supported and has a rough explanation of ***why*** it was chosen.	The write-up is poorly written with no organization by topic sentence, body, and conclusion. ***Recorded questions are not appropriate and do not help work through the case.*** Diagnosis has no support and is not clearly understood.

D. APPENDIX 4 – STUDENT WRITING SAMPLE

Initial Sample

Definitions:

- Paresis: partial loss of voluntary movement
- Broken hip: fracture on the neck of the femur
- High blood pressure: pressures higher than 140/90
- Motor neuron: lower motor neurons from ventral horn
- Sensory neuron: primary afferents

Timeline:

- Fast
- Happened last night

Systems involved:

- Nervous: intact
- Cardiovascular: severed
- Musculoskeletal: intact

Unique to case:

- Emotional instability
- Paresis in abdomen
- Upper limb is not affected

Questions used to come to conclusion:

- What supplies motor and sensory to lower limb?
- What nerves run near hip joint?
- What causes emotional instability?
- **Should have asked**: Where are the sensory and motor for lower limb close to one another? **Answer:** pre- and post-central gyri

Differential diagnosis:

Given loss of sensory and motor input to **left** lower limb, **right** anterior cerebral artery ischemia caused the sensory and motor cortices of the contralateral **(left)** lower limb to be without blood flow for a short amount of time (last night). The lack of flow led to a fast onset of motor and sensory paresis to limb.

<u>Final Sample</u>

Relevant Definitions:

- Pin prick: tests pain sensation
- Double vision: when more than one image is transmitted to cortex
- Nystagmus: could be due to a vestibular nuclei lesion since voluntary eye movements are intact

Case:

A 58-year-old male presents to the physician as alert and oriented following an episode 5 days prior. During the episode, the patient experienced what felt like the room was spinning. He stated that he felt he could not voluntarily control his left side of his body. Both lower limbs were numb to a degree. He experienced left side face numbness, double vision and trouble with speech. Upon secondary examination following the episode, the patient is still experiencing lack of left side coordination during intention movements. He also has nystagmus present when he gazes laterally on both sides. His right foot is numb and is not experiencing pain sensation. Deep tendon reflexes are intact bilaterally in all four limbs. He is still experiencing left facial numbness and a loss of pain and vibration sensation on the left side of the face as well.

The timeline for this patient is fast, as he experienced the symptoms suddenly. The systems involved would be cranial nerves innervating the face, the anterolateral system and the cerebellum. It is unique that the patient has regained some of the functions he lost during the episode, such as the double vision.

Questions and Diagnosis:

Since the patient was experiencing left sided facial numbness and loss of pain and vibration sensation, I began by asking which cranial nerve carries pain and vibration sense from the left side of the face? Cranial nerve V carries pain sensation to the rostral portion of the left spinal nucleus of V and vibration sensation to the left principle nucleus of V. Then I moved on to the loss of pain sensation the patient was experiencing in the right lower limb, specifically the foot. I asked what carries pain sensation from the right lower limb? The left anterolateral system carries pain, temperature and crude touch sensation that is ascending from the right lower limb. I then moved on to the loss of coordination the patient was experiencing in intention movements on the left side of the body. I asked what controls intention movements, such as the nose to fingertip maneuver or the stroking of the shin with the heel? The cerebellum controls coordinated intention movements. I then addressed the patients initial struggle with the room spinning and double vision that ultimately was reduced to nystagmus. I asked what can cause nystagmus? Nystagmus can be caused by a lesion to a vestibular nucleus, programmed pattern generators or the cerebellum. It is most likely in this patient that the vestibular nuclei were affected by the lesion. I then concluded that the affected areas were the rostral portion of the left spinal nucleus of V carrying pain sensation from the left face, the left principle nucleus of V carrying vibration sensation from the left face, the posterior portion of the left anterolateral system carrying pain information from the right foot/leg, the left vestibular nuclei which explains the nystagmus, and the left cerebellar peduncles which carry information that aids in coordinating intention movements. My next question was where in the brainstem are all of these components located together? I narrowed this to the left caudal pons. Finally, I asked which artery supplies the area that was damaged by the lesion? This would be the left anterior inferior cerebellar artery. In conclusion, the patient experienced a lesion to the left anterior inferior cerebellar artery. This explains why the symptoms appeared quickly, an arterial bleed is fast. A lesion to the left AICA also explains the damage to the left rostral spinal nucleus of V, left principle nucleus of V, the left anterolateral system, the left vestibular nuclei, and the left cerebellar peduncles. It is unique that the patient was able to regain function of some of the cranial nuclei that were originally compressed by the lesion.

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