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Anatomy and Physiology Research in a Community College

Provision of a Word Bank for Lab Practicals

Optimal Dosing of Anesthetic in Xenopus leavis Frogs

The Impact of Think-Pair-Share

Unraveling the Epididymis

Human Hip Dissection Based on a 19th Century Experiment

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Promoting Excellence in the Teaching of Human Anatomy & Physiology

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Clickers in a Community College Classroom: An Initial Foray into Community College Biology Education Research

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Abstract
One strategy to transform the high attrition rates among community college (CC) students is for CC instructors to utilize the teaching practices shown to most likely lead to student success. CC students and faculty are underrepresented in biology education research (BER), with only 3% of BER articles addressing CC-specific issues (Schinske et al. 2017). This study examines whether the addition of an electronic student response system (SRS), and its proposed ability to facilitate group discussion, would enhance the effects of peer instruction on student performance in a community college anatomy and physiology course. Unit exam scores of students utilizing clickers vs. written responses were compared to determine if the addition of clicker technology to peer instruction increased performance. A MANOVA test revealed no significant differentiation in exam scores between groups. This implies that CC students may respond dissimilarly to previously studied students and that more educational research must be done at community colleges. https://doi.org/10.21692/haps.2019.030

Key words: active learning, clickers, community college, educational research

Introduction

The community college (CC) student population is unique among undergraduate students (American Association of Community Colleges [AACC] 2019). They are more diverse in terms of race or ethnicity as well as socioeconomic background. Community college students tend to be older and have family obligations. Community colleges enroll a diverse population of military-affiliated students, including those on active duty, reservists, and veterans. CC students are more likely to enroll part-time and work while attending school. These factors may create challenges for college success.

Community colleges provide an essential pathway to postsecondary education for many who would not attend college otherwise. However, there is a high rate of attrition among CC students, and most do not complete a credential or degree (American Association of Community Colleges [AACC] 2019). One strategy to transform this outcome is for community college instructors to utilize the teaching practices shown to most likely lead to student success.

One teaching practice that has been shown to increase student performance in science, technology, engineering, and math (STEM) courses is active learning (Freeman et al. 2014; Hake 1998; Prince 2004), including anatomy and physiology (Rao and DiCarlo 2001; Michael 2006; Shaffer 2016). Generally, active learning is any learning activity in which the student participates or interacts with the learning process. One active learning technique, peer instruction (PI), involves the instructor asking students carefully designed questions related to known areas of confusion or misunderstanding. Students answer the question individually and then work in small groups to arrive at a consensus. This small group discussion results in students discussing the concepts and possibly providing clarification to group members. The instructor leads a full class discussion to review and provide further clarification. PI has been shown to be effective at community colleges (Fagen et al. 2002; Lasry et al. 2008).

One proposed method of enhancing peer instruction is to utilize electronic Student Response Systems (SRS). SRS are instructional technology tools that assist in generating engagement in the classroom by allowing the creation of interactive presentations. Students can respond to the questions or problems posed in the presentation by using a SRS device. The SRS gathers the data and can display summaries of students' responses as a histogram. Answers are also stored for later viewing, grade reporting, further analysis for both question and topic coverage, and educational research.

Studies have cited an improvement in class scores related to SRS usage (Freeman et al. 2007; Morling et al. 2008; Mayer et al. 2009). These studies introduced SRS in conjunction with an active learning technique, which resulted in comparing a traditional lecture-based classroom with a classroom utilizing

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SRS-assisted peer instruction. It is unclear as to whether improvements in student learning were associated with the clickers, the utilization of active learning techniques, or some combination. Other studies have indicated that additional gains in student learning occurred when SRS were used in conjunction with reliable active learning techniques (Duncan 2005; Knight and Wood 2005; Caldwell 2007). As the specific effect of SRS is still unclear, our study used peer instruction across all groups to parse out whether there would be a significant difference in unit exam grades among students who responded to questions by electronic SRS (clickers) or written response. The primary research goal of this project was to investigate whether the addition of SRS, and its ability to further facilitate group discussion, would enhance the effects of peer instruction on student performance in a community college anatomy and physiology course.

The secondary goal of this project was to expand the available pool of biology education research that can be used to increase community college student success. The studies mentioned earlier were conducted in large classrooms in four-year college and university settings, which are different from CCs in both student populations and faculty responsibilities. Community college instructors are often unique among post-secondary educators. For instance, CC faculty typically have heavier teaching loads. While their job assignments focus principally on pedagogy, they also include service and professional development with little to no expectation of conducting research (Cohen and Brower 2003). This heavy teaching load as well as lack of access to teaching and learning centers and professional development funds may complicate the creation and application of active learning techniques in CC classrooms (Smith 2007). According to Schinske et al. (2017), community college students and faculty are under-represented in biology education research. Only 3% of biology education research articles address CC-specific issues or are even authored by CC faculty (Schinske et al. 2017).

Methods

The participants in this study were voluntarily enrolled students in one of two traditional, daytime, face-to-face lecture sections of human anatomy and physiology at Anoka-Ramsey Community College (ARCC) during the spring semester of 2019. This course was the first half of a two-semester sequence, and included a comprehensive study of body organization: homeostasis, tissues, integument, skeletal system, muscular system, nervous system, special senses, and endocrine system. This human anatomy and physiology course was aimed primarily at allied health students. A passing grade of "C" or better in an introductory majors-level biology course was a prerequisite for enrolling in this anatomy and physiology course.

To be included in the study, students had to give their consent, participate in all five active learning exercises, and complete all five major summative assessments in the form of lecture unit exams. Sixty-two students fulfilled these criteria. Of the participants, 62.9% registered as pre-Nursing, pre-Physical Therapy Assistant, or other health related majors. An additional 4.8% registered for the course as an elective in a science major. The remaining 32.2% either were completing an Associate of Arts degree or had not yet identified a major (Figure 1).

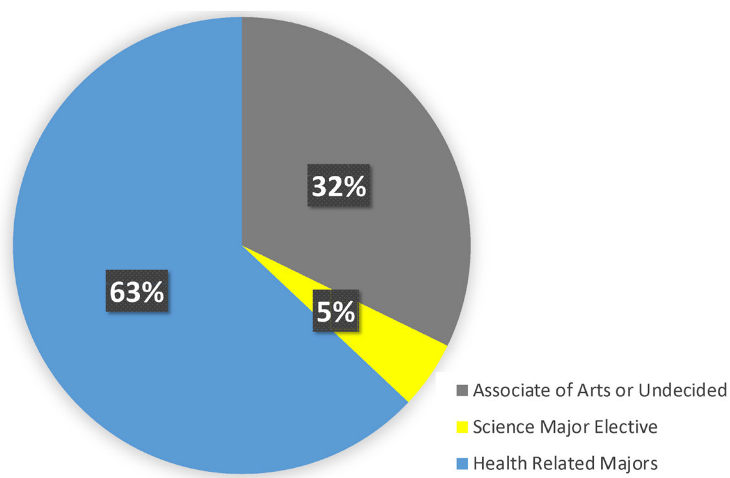

Figure 1. *The distribution of students participating in this study by major.*

The course consisted of two lecture sections, with approximately 48 students each, which were divided into two lab sections of approximately 24 people each (Figure 2). Each lecture section and its two corresponding labs were taught by the same instructor. Each lecture section met as a group for a total of 150 minutes per week, either for three 50-minute lecture periods or two 75-minute lecture periods. The lab sections met for an additional 160-minute laboratory session per week.

Peer instruction, a known effective teaching practice at CCs, was added to all lab sections. One lab from each section utilized SRS technology (referred to as clickers hereafter) and the other utilized a paper and pencil response (referred to as written response hereafter). The clicker sections consisted of 29 participants, 27 of which were female (93.1%) and two were male (6.9%). The average age was 24.4 years, with a range of 18–44. The written response sections consisted of

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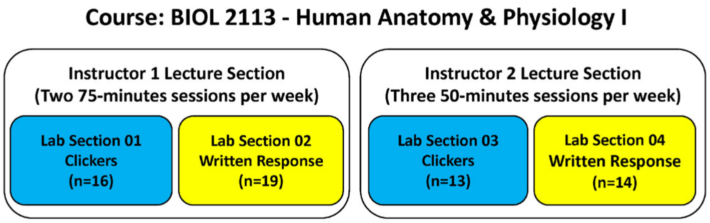


***Figure 2.** The organization of students in this study.*

33 participants, 27 of which were female (81.8%) and six were male (18.2%). The average age was 25.7 years, with a range of 19-54 (Table 1).

At ARCC, faculty members have two options for SRS: a TurningPoint device provided by the information technology department or a mobile platform (e.g., Socrative, Kahoot). The TurningPoint device includes the "clicker" (for the student) and a receiver (for the instructor); a mobile platform allows students to respond using their own networked devices such as laptops, tablets, or smartphones. As our student population is socioeconomically diverse, we chose to provide clickers for the sake of fairness and equal access.

To ensure the same instructional conditions for all students, students in both the clicker and written response sections were presented with the same class materials and completed the same in-class activities and assignments prior to the experimental activities. By using the same experimental activity questions for both sections, any difference in unit exam score could be attributed to the effects of the SRS and not to the content addressed in the questions or merely to directing the student's attention to specific course content.

	Clickers	Written Response
Participants, n	29	33
Gender		
Female, n (%)	27 (93.1)	27 (81.8)
Male, n (%)	2 (6.9)	6 (18.2)
Age (years)		
Mean ± SD	24.4 ± 7.7	25.7 ± 8.9
Range	18 - 44	19 - 54

***Table 1.** Demographics of the students in this study.*

The students in each lab section self-selected into semester-long groups of three or four, depending on class size. Each individual student and each group in the clicker labs was assigned a uniquely labeled clicker for grading purposes. These students received clicker training prior to the first experimental activity to reduce anxiety regarding unfamiliar technology as well as to minimize user error.

Five experimental activities were conducted, one prior to each unit exam, throughout the semester. Each experimental activity consisted of five multiple-choice questions, similarly structured to those utilized in the lecture unit exams, pertaining to material covered in previous lectures (Figure 3).

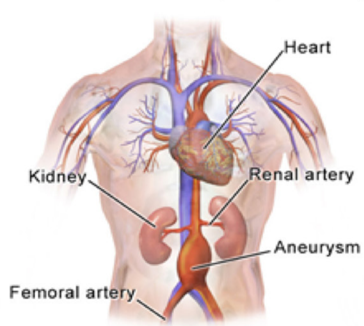
A 65-year-old male, with a history of high blood pressure, presents with sudden, severe abdominal pain he describes as "sharp tearing or stabbing" in character. He complains of being lightheaded, has vomited twice in the last hour, and is sweating. A CT scan is ordered and an abdominal aortic aneurysm (AAA) is diagnosed.

The aorta is the major blood vessel that supplies blood to the body. It is about the thickness of a garden hose and runs from your heart through the center of your chest and abdomen. The aorta withstands high blood pressure as it directly receives blood ejected from the heart. The aorta must stretch or expand to accept this blood and then recoil or return to its original size, which continues to force the blood through the body.

An abdominal aortic aneurysm is a permanent localized dilatation (enlarged area) in the lower part of the aorta. If left untreated, the aortic wall continues to weaken and becomes unable to withstand the forces of the blood pressure. This results in progressive dilatation and rupture, which is a catastrophic event associated with a mortality of 50 – 80%.

Which component of the connective tissue of the aorta is most likely involved?

A) collagen fibers
B) elastic fibers
C) ground substance
D) reticular fibers



"Abdominal Aortic Aneurysm Location" by Bruce Blause is licensed under CC BY-SA 4.0

"Aneurysm Aorta With Arrows" by Bakerstmd is licensed under CC BY-SA 4.0

***Figure 3**. An example of a PI question used in this study.*

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The students answered the questions individually, engaged in group discussion regarding the questions, and then answered the same questions as a group upon reaching a consensus. To ensure student participation and investment, the experimental activities were worth a total of 5% of the students' overall class score. Full credit was earned if the individual and group answers were correct, half credit was earned if either the individual or group answer was correct, and no credit was earned if neither the individual nor group answer was correct. This grading scheme was to encourage participation, presentation of arguments, and advocating for the right answer.

The students were given a maximum of three minutes to answer each question individually, and then a maximum of five minutes to answer as a group. Speaking was not allowed during the individual portion of the activity, and group discussion did not begin until all students had answered the question individually. The experimental activities typically lasted approximately 15 - 30 minutes.

The students in the written response sections recorded their individual and group answers on a paper answer form. The individual answer forms were visually examined to ensure that each student marked an answer before group discussion began. Following group discussion, a consensus response was recorded on the group answer form.

Like the written response sections, participants in the clicker sections answered the questions independently first; however, their anonymous responses were shown to the class as a histogram. Upon viewing the histogram, the students were allowed to discuss the questions with members of their group. Once a consensus was reached, a second response was submitted using the group clicker.

Subsequent to the completion of the five questions, all electronic and paper submissions were collected for grading at a later time. Instructors then reviewed each question with the class, explaining why each answer option was either correct or incorrect to ensure equivalent review and reinforcement of the material. Instructors utilized a common PowerPoint presentation to ensure consistent coverage of the material between lab sections. The review activities typically lasted approximately 15 - 30 minutes.

Each instructor's students, both clicker and written response sections, took identical multiple-choice unit exams during the same class period. The unit exam average scores of clicker and written response sections were then compared using the multivariate test (MANOVA). Demographic data and student grades were reported using descriptive statistics including mean and standard deviation.

This study was reviewed and deemed to be routine instructional research by the chair of the ARCC Institutional Review Board and was, therefore, exempt from IRB review. Informed consent was obtained from all participants. All participants were 18 years of age or older and did not represent any known vulnerable populations.

Results

Unit exam scores of clicker vs. written response students were compared to determine if there was a relationship between clicker usage associated with the active learning exercises and increased performance on exams. The data collected from the clicker course sections and from the written response course sections were combined for this analysis (Figure 4). A MANOVA test revealed no significant differentiation between clicker and written response groups, F<1. Exam scores were also compared between the different instructors of the two lecture sections; these results indicated no differentiation, F<1 (Figure 5).

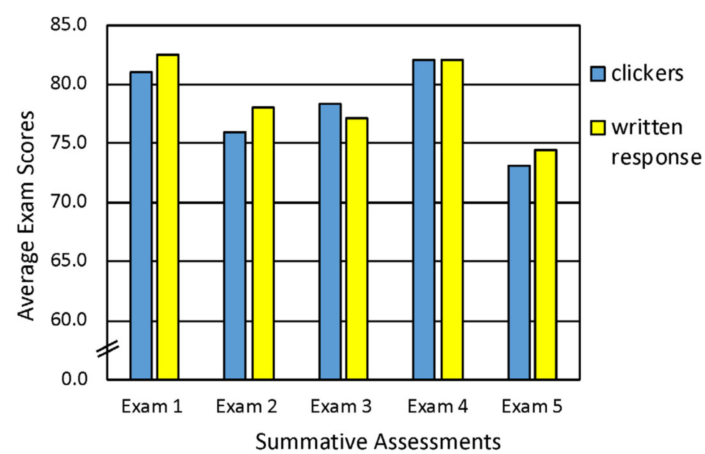

Figure 4. *Comparison of average exam scores by experimental method.*

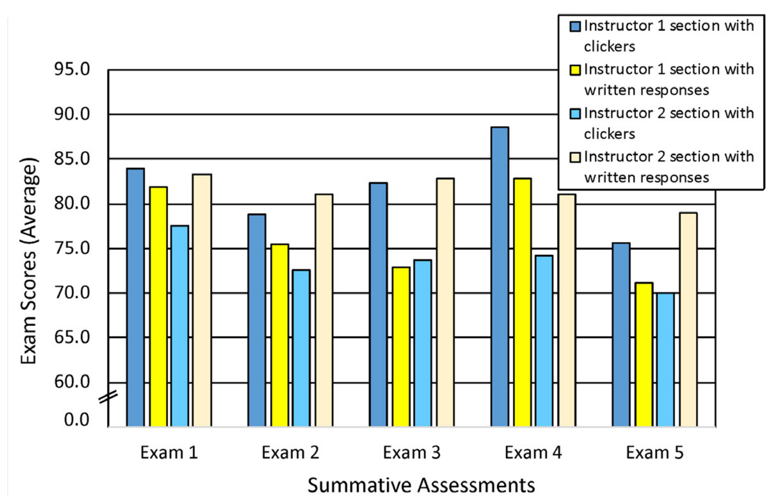

Figure 5. *Comparison of average exam scores by section.*

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Discussion

The primary mode of teaching in community colleges is traditional lecture or lecture utilizing PowerPoint (Smith and Valentine 2012). However, active modes of instruction have been shown to promote learning over traditional lecture (Freeman et al. 2014). Freeman et al. (2014) found that undergraduate students in classes utilizing traditional lecture were 1.5 times more likely to fail than students in classes employing active learning methods. Most studies concerning the use of active learning strategies and techniques have been primarily tested at four-year and research-based institutions. One exception, peer instruction, has been tried and shown to be effective at community colleges (Fagen et al. 2002; Lasry et al. 2008). For this reason, peer instruction was chosen to be the form of active learning to which clickers would be added for this research project.

The results of this study indicated that the students using the clickers did not receive any additional educational benefit when compared with students using the written response method. The lack of difference between the different instructors' lecture sections gave further credence to the conclusion that clickers, when utilized in this manner, do not produce an added benefit to active learning techniques.

Limitations

Since the efficacy of clickers has been supported in other environments (Freeman et al. 2007; Morling et al. 2008; Mayer et al. 2009), the authors propose several explanations for the lack of an increase in exam scores associated with the use of clickers in this project. First, this project had a small sample size, with only sixty-two participants ((N = 62, 29 with clickers and 33 written response). This may have had an impact on our results as it is well supported that a smaller sample size increases bias or at least undermines the reliability of one's conclusions. Second, this study may have used an ineffective implementation of clickers, as this was the authors' first foray into discipline-based educational research (DBER) and they were ignorant of the elements necessary to produce the beneficial effects of clickers. Thus, methodological flaws may have compromised the validity of this study's findings (Stains and Vickery 2017). Third, the use of peer instruction may have been so influential that it was not possible to see any additional beneficial effect from the clickers.

While the way in which clickers were implemented in this study was not found to be effective in positively influencing student scores, the differences between this study's findings and those of clicker studies conducted at four-year undergraduate institutions illustrates the importance of conducting research on the effectiveness of instructional tools, such as clickers, specifically within the CC environment.

Conclusions

The authors would like to offer the following insights for community college instructors interested in conducting educational research or adopting active learning into their courses. First, educational research does not require inventing novel methodology. Research conducted at four-year undergraduate institutions regarding the effectiveness of active learning instructional practices can also be conducted at community colleges. Furthermore, this research should be conducted at community colleges due to the unique student population. Second, active learning does not have to be expensive. The authors of this study used dormant instructional technology as well as pencil and paper. Third, adopting active learning in the classroom takes time, which can be taxing on the already heavy teaching load of a CC instructor. However, shifts toward active learning do not have to be incorporated into every class or all at once. Any change toward active learning may provide positive effects for your students.

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Literature Cited

American Association of Community Colleges. 2019. Fast facts. [accessed 2019 May 10]. Available from: http://www.aacc.nche.edu/research-trends/fast-facts/

Caldwell JE. 2007. Clickers in the large classroom: current research and best-practice tips. *CBE Life Sci. Educ*. 6(1): 9–20. doi: 10.1187/cbe.06-12-0205.

Cohen AM. 2003. The American community college. San Francisco (CA): Jossey-Bass.

Duncan D. 2006. Clickers: A new teaching aid with exceptional promise. *Astronomy Education Review*. 5(1): 70–88. doi: 10.3847/AER2006005.

Fagen AP, Crouch CH, Mazur E. 2002. Peer instruction: Results from a range of classrooms. *The Physics Teacher*. 40: 206-209. doi:10.1119/1.1474140.

Freeman S, O'Connor E, Parks, JW, Cunningham, M, Hurley, D, Hurley D, Haak, D, Dirks C, Wenderoth MP. 2007. Prescribed active learning increases performance in introductory biology. *CBE Life Science Education*, 6(2): 132-139. doi: 10.1187/cbe.06-09-0194

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Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, and Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. *PNAS* 111(23):8410-8415. doi: 10.1073/pnas.1319030111.

Hake RR. 1998. Interactive-engagement versus traditional methods: A six-thousand-student survey of mechanics test data for introductory physics courses. *Amer J of Physics*. *66*(1): 64-74. doi: 10.1119/1.18809.

Johnson, DW, Johnson RT, Smith KA. 1998. Cooperative learning returns to college: What evidence is there that it works? *Change: The Magazine of Higher Learning* 30(4): 26-35. doi: 10.1080/00091389809602629

Knight JK, Wood WB. 2005. Teaching more by lecturing less. *Cell Biol. Educ*. 4: 298–310. doi: 10.1187/05-06-0082.

Mayer RE, Stull A, DeLeeuw K, Almeroth K, Bimber B, Chun D, Bulger M, Campbell J, Knight A, Zhang H. 2009. Clickers in college classrooms: Fostering learning with questioning methods in large lecture classes. *Contemporary Educational Psychology*. 34: 51-57. doi: 10.1016/j.cedpsych.2008.04.002.

Michael J. 2006. Where's the evidence that active learning works? *Adv Physiol Educ* 30: 159-167. doi: 10.1152/advan.00053.2006.

Morling B, McAuliffe M, Cohen L, DiLorenzo TM. 2008. Efficacy of personal response systems (clickers) in large, introductory psychology classes. *Teaching of Psychology*, 35:45-50. ISSN: 0098-6283 print / 1532-8023 online. doi: 10.1080/00986280701818516

Lasry N, Mazur E and Watkins J. 2008. Peer instruction: From Harvard to community colleges. Am. J. Phys., 76, Pp. 1066–1069.

Prince M. 2004. Does active learning work? A review of the research. *J. Engr. Education*. 93(3): 223-231. doi: 10.1002/j.2168-9830.2004.tb00809.x.

Rao SP and DiCarlo SE. 2001. Active learning of respiratory physiology improves performance on respiratory physiology examinations. *Adv Physiol Educ*. 25: 127-133. doi: 10.1152/advances.2001.25.2.55.

Schinske JN, Balke VL, Bangera MG, Bonney KM, Brownell SE, Carter RS, Curran-Everett D, Dolan EL, Elliott SL, Fletcher L, et al. 2017. Broadening participation in biology education research: Engaging community college students and faculty. *CBE Life Science Education*. 16(2), mr1. doi:10.1187/cbe.16-10-0289.

Shaffer JF. 2016. Student performance in and perceptions of a high structure undergraduate human anatomy course. *Anat Sci Educ*. 9: 516-528. doi:10.1002/ase.1608.

Smith A. 2007. Professional development issues for community colleges. Peer Review. 9(4). [accessed 2019 June 2]. Available from https://www.aacu.org/publications-research/periodicals/professional-development-issues-community-colleges.

Smith DJ, Valentine T. 2012. The use and perceived effectiveness of instructional practices in two-year technical colleges. *J Excellence in College Teaching*. 23: 133-161.

Stains, M, Vickrey T. 2017. Fidelity of implementation: An overlooked yet critical construct to establish effectiveness of evidence-based instructional practices. *CBE Life Science Education*. 16, rm1-11. doi: 10.1187/cbe.16-03-0113.

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Community College Anatomy and Physiology Education Research: Conducting Research Where It Ought to be Done

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Abstract
Evidence Based Instructional Practices (EBIPs) have been shown to increase student engagement in college classrooms. Education research conducted to date on the effectiveness of these EBIPs and their impact on students' has largely focused on four-year and research-intensive institutions, and community colleges represent a significant gap in the literature. The NSF-funded Community College Anatomy and Physiology Education Research (CAPER) project has attempted to narrow that knowledge gap through instruction, mentoring, and research support teams. To date, two cohorts of community college instructors (six participants each year) have participated in an online course on education research, which culminates in the completion of a research proposal. Participants receive coaching and mentorship through the development and implementation of their research projects at their respective institutions. Data collected to date measures the impact that each EBIP has on student anxiety and academic self-efficacy. The purpose of CAPER is not only to gather data on the EBIP implementation and effectiveness in community college classrooms, but also to gather data on long-lasting change in instructional methods used by community college instructors engaging in this research. Through this research, we are contributing to the body of literature that is currently lacking representation of community college populations. In addition, we are identifying tools and resources that may increase the likelihood that community college faculty will engage in student-centered learning techniques in their classrooms. https://doi.org/10.21692/haps.2019.029

Key words: anatomy and physiology, teaching and learning, community college, education research

Introduction

The student population at two-year schools is quite different from that at four-year research universities. According to the National Center for Education Statistics (Radwin 2017), Community College (CC) students are more likely to be older, to have military experience, to be raising children, and to be working in addition to attending school. Many are members of visible minorities and are the first in their family to pursue post-secondary education. All of these factors are associated with high attrition rates; less than 40% of students complete their program within six years (Bailey et al. 2015), and less than 15% of entering students earn a bachelor's degree within six years (Jenkins and Fink 2016). Yet, as publicly funded institutions, CCs are often limited in the resources they can offer struggling students (Zeidenberg 2008).

CC instructors similarly constitute a distinct population: they are more likely to be part-time, less likely to have a tenure track position, and frequently juggle adjunct positions at multiple schools or have other significant professional or family commitments (Center for Community College Student Engagement 2014), and they typically teach multiple sections of anatomy and physiology each semester. Clearly, help is needed for both the instructors and the students. The Science of Teaching and Learning (SoTL) is an area of research that should motivate and guide CC instructors to increase their teaching effectiveness. However, CC instructors are often less well-equipped than their university counterparts to take advantage of recent developments in SoTL, lacking access to teaching and learning centers, professional development funds, and scientific journals that are not open access (McFarland and Pape-Lindstrom 2016).

One objective of SoTL is to identify teaching practices that help students succeed. Evidence Based Instructional Practices (EBIPs) are pedagogical approaches that have been documented to improve student outcomes (Stains and Vickrey 2017; Center for Research on Lifelong STEM learning, Oregon State University). Broadly speaking, the landmark article "Active learning increases student performance in science, engineering and mathematics" established student-centered pedagogy, or active learning, as an EBIP (Freeman et al. 2014). Active learning techniques may be particularly relevant to CC students, since they have been identified as a means of encouraging inclusivity and reducing the achievement gap faced by underrepresented demographics in STEM (Snyder et al. 2016). However, as Schinske et al. (2017) clearly points

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out, only 3% of biology education research articles address CC-specific issues or are even authored by CC faculty. Thus, with a few notable exceptions such as peer instruction (Fagen et al. 2002), the recommendations for incorporating different pedagogies have primarily been tested in 4-year and research-based institutions, which frequently have a different population of both students and instructors. In order to be fully validated, each EBIP needs to be tested in a variety of real-world institutions including community colleges (Stains and Vickrey 2017).

The NSF-funded Community College Anatomy and Physiology Education Research (CAPER) project (Figure 1) uses a collaborative approach to increase the use of EBIPs in CCs and to gather data as to their impact in CC populations. To work towards this goal, twelve community college instructors, organized into two cohorts, are undertaking small-scale research projects that they design and implement within their own Anatomy and Physiology classrooms. This brief article describes the goals and design of the CAPER project, presents selected preliminary results from Year 1 of the project, and outlines future objectives of our research group.

Fig 1. *The CAPER logo. Art credit: Lauren Jones*

Project Design

Each cohort of six instructors spends one year in the CAPER project (Fig. 2). The first phase involves a 1-credit HAPS-I course titled An Introduction to Education Research Methods, in which participants review information about the learning process, study various instructional practices, and look at the basics of experimental design and analysis (Human Anatomy and Physiology Society 2019). This course was developed by Valerie O'Loughlin in 2015 and was offered for the third time in 2019. The final product of the HAPS-I course is a modest, classroom-based research proposal. This proposal includes a research question, implementation strategy, and appropriate data collection instruments and procedures. It also provides the basis for the application to their school's Institutional Review Board (IRB). Phase 2 (Implementation) occurs in the subsequent (spring) semester; instructors implement their research proposal in their own classroom. Finally, in the dissemination phase of the project, instructors present the preliminary findings in a poster at the HAPS annual conference and subsequently write a research paper for the HAPS Educator.

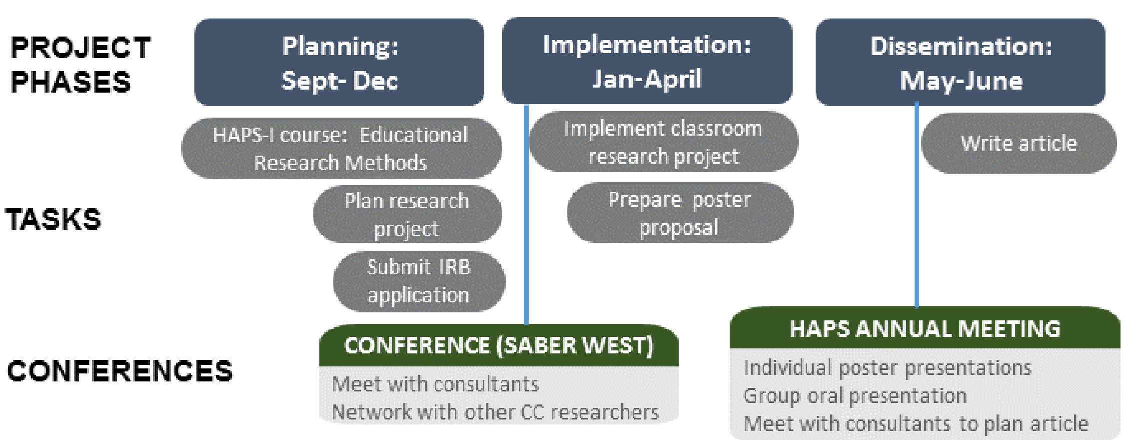

Fig 2. *The CAPER timeline. SABER is the abbreviation for the Society for the Advancement of Biology Education Research.*

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As shown in Figure 3, CC instructors are provided two levels of help throughout the duration of the CAPER project. First, instructors are grouped into pairs based on geographic location or intervention of interest and paired with a mentor with experience with EBIPs and education research. Second, all three mentor-instructor triads are supported by qualitative and quantitative analysis consultants with considerable experience in social science methodology, the course instructor(s), and a writing consultant who is currently the Editor in Chief of the *HAPS Educator*. In this iteration of CAPER, only one mentor is from a community college, and all consultants and course instructors are from universities. However, as discussed later in this article, we hope to increase the number of CC instructors in CAPER leadership positions in the future.

***Fig 3.** Each pair of CC instructors worked with a mentor and had access to consultants and the HAPS-I course instructor (Gerrits 2019).*

In concert with their individual projects, all participating CC students will complete a common survey at the beginning and the end of the implementation semester. This survey asks students to rank different classroom teaching techniques in terms of how much anxiety they perceive in response to each and how much they think the technique contributes to their learning (modified from Hull et al. 2018). The survey also evaluates student personality measures such as social anxiety (Connor et al. 2001) and academic self-efficacy (McIlroy 2000). Individual instructors can use aspects of the data from their class in their project, and by pooling the data of all instructors we will be able to generate relatively robust data to address questions such as the impact of social anxiety on perceptions of active learning. This collaborative effort uses a different model of promoting education research in community colleges by incorporating CC instructors into multi-institutional research teams coordinated by researchers at four-year or research-intensive institutions.

Year 1: What Have We Accomplished?

Working collaboratively, twelve of the thirteen individuals, including instructors, mentors, and consultants (Figure 3) involved in Year 1 of the CAPER project have generated data regarding the effectiveness of EBIPs in community college populations. Each participant incorporated a new-to-them EBIP into their classroom such as student response systems, think-pair-share, or formal groups. With the support of quantitative and qualitative analysis consultants, participants measured the impact of the EBIP on one or more variables, such as grades, student anxiety, academic self-efficacy, or willingness to work with others. Involvement in the CAPER project has allowed some of these individuals to collect data that has led to manuscripts published in this issue of the *HAPS Educator*. For example, Nancy Djerdjian and Shawn Magner from Anoka Ramsey Community College examined the effects of student response systems on facilitating group discussions and Melaney Farr from Salt Lake City Community College documented her research on the Think-Pair-Share teaching method.

In addition to the individual research projects led by each CC instructor, the research team used the pooled data from the student surveys to investigate the impact of instructional practices in different student populations. One of the broader questions began as the individual research project of Nancy Barrickman from Salt Lake Community College regarding differences between continuing and first generation students, and resulted in a manuscript to be published in the *Journal of Microbiology and Biology Education* (JMBE).

During the 2019 HAPS Conference in Portland, four of the six CC instructors as well as the mentors engaged in a panel discussion with other members of HAPS entitled The NSF & HAPS CAPER Project: Research in Community College A & P Classrooms. Facilitated by Jenny McFarland of Edmonds Community College, audience questions focused on the feasibility of busy community college instructors trying to engage in one more thing i.e. research. The CC instructors spoke honestly about the difficulties associated with setting aside time for research and securing IRB approval, but also emphasized that research was indeed possible if given enough support. The instructors also appreciated that CAPER provided support for their own experiments rather than simply involving them in large-scale efforts coordinated by researchers at large universities.

Year 1: What Have We Learned?

Our preliminary work highlights the potential of CC research ventures, not only to confirm or nuance work done in four-year schools but also to generate and answer distinct and universally relevant research questions. The most interesting results from our analysis, involving how students' individual differences impact their perceptions and responses to active learning techniques, reflected the greater diversity of the CC student population compared with that at research-intensive and four-year universities (Hood et al. 2019a; Hood

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et al. 2019b). Moreover, involving the end-users in all phases of research, from the formulation of research questions to dissemination efforts (Jacobs 2016), provides distinct perspectives. CC instructors know their student populations and develop unique research questions, as borne out by the investigation of generational status initiated by one of our participants (Hood et al. 2019a).

The barriers facing CC educational researchers are significant. As documented by Schinske et al. (2017), these include the lack of time, infrastructure, administrator/peer support, and incentives. We attempted to address the lack of infrastructure and administrative/peer support by providing CC instructors with mentors and consultants, and the lack of incentives by offering participants a monetary reward of $500 for completion of the project and travel support to attend two conferences. Ideally our participants would have received a teaching relief to address the time constraints imposed by heavy teaching loads; however, arranging course releases requires a level of administrative buy-in that was not feasible.

Despite the mitigating efforts, the research project remained a challenging task for participants for various reasons. Some instructors were overambitious with their original project ideas, assuming that they were required to develop a novel and innovative project using gold-standard experimental designs and quantitative analyses. Others displayed skepticism regarding the utility of qualitative measures and experimental designs not involving control groups, which may partially reflect their previous lab research experiences. Finally, the statistical analysis was often challenging. This latter concern is not surprising because the degree of sophistication of statistical analysis methods used in educational research is increasing substantially, so individuals not trained in education research rarely have the background to perform their own statistics. While we attempted to mitigate this difficulty by providing a quantitative analysis consultant who was very comfortable with advanced statistical analysis, instructors felt less connected with their projects. We are exploring a different approach with the second year cohort, emphasizing simpler statistical techniques and more straightforward research questions. In addition, we are developing decision tree graphics to help select the correct test for common research questions relating to classroom practices (Fig. 4A). Accompanying these decision trees are "plug and play" Excel templates, in which participants can enter their data and the spreadsheet will automatically generate graphs and statistical analyses (Fig. 4B). Participants are empowered to enter and analyze their own data, with the quantitative analysis consultant available for back up.

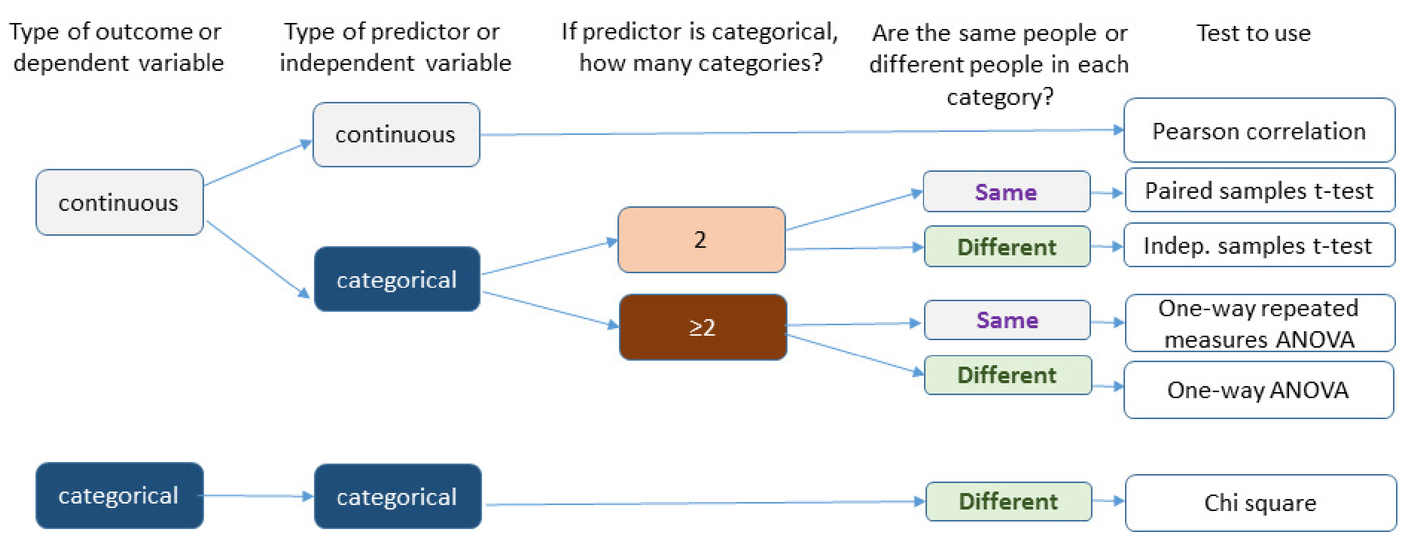

Fig 4a. *A decision tree that can be used by novice researchers to decide on an appropriate statistical test. Modified from Field (2013).*

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continuous variable 1	
participant ID	e.g., academic self-efficacy rating
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
…	
mean score	#DIV/0!
standard dev.	#DIV/0!

continuous variable 2	
participant ID	e.g., reported study habits
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
…	
mean score	#DIV/0!
standard dev.	#DIV/0!

Pearson correlation statistic	#DIV/0!
degrees of freedom (df)	calculated from the number of participants who have data for both of the variables being correlated – 1

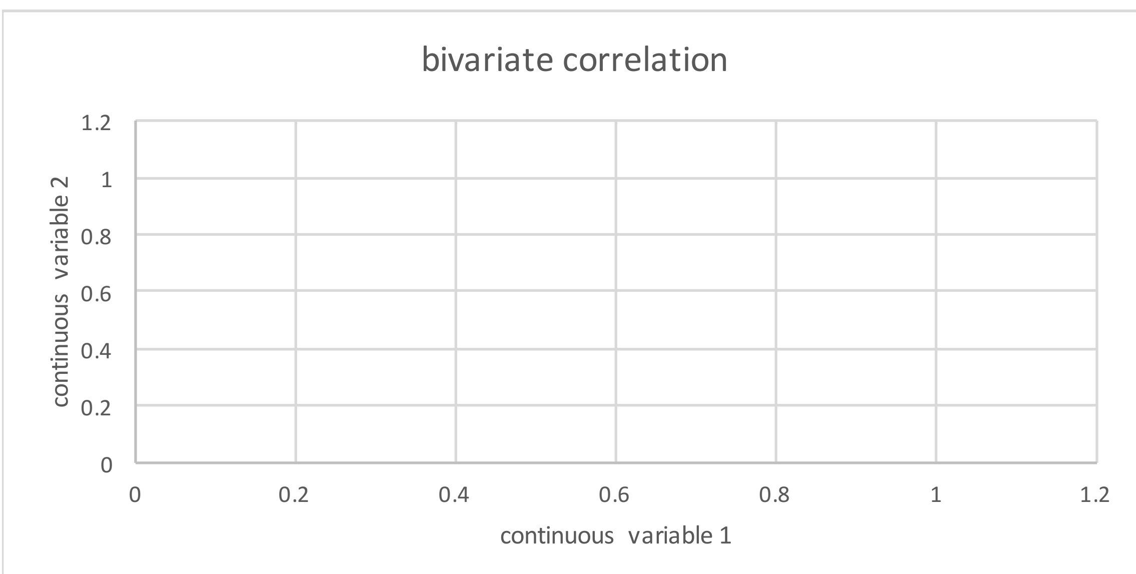

Fig 4b. *A sample Excel template for statistical analysis. Instructors can enter their values, and Excel will perform correlation analysis and generate a simple graph that can be modified by the instructor.*

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Dissemination of research results is also a daunting task, which we attempted to address via writing mentors. We came up against an interesting conundrum; the increasingly rigorous publication standards for statistical analysis increases legitimacy of educational research as a whole, yet potentially dissuades educators hoping to engage in SoTL without social science training. Schinske et al. (2017) notes efforts by some journals to have special CC research sections. Data on smaller populations and/or with less reported statistical significance than what would be acceptable in traditional research domains may still have a place in educational research, by providing an achievable target for potential novice educational researchers.

The lack of consistency in IRB procedures between different community colleges was also a source of confusion and anxiety. It should be noted that, once identified, the CC IRB officials were very helpful; thus, the second year participants were encouraged to identify and speak personally with the relevant individual very early in the project. While we had hoped that IRB approval at a research-intensive institution would be acceptable to the IRBs of the CCs, this did not prove to be the case. Each school required a separate and complete application, even for anonymous data. We facilitated the process by preparing a database of IRB applications prepared for similar projects, but receiving IRB approval remains a daunting task and a potential barrier. In the future, we would like to establish a database of IRB application templates for use by all HAPS members.

Despite the difficulties faced by CC instructors, they found the experience valuable. Furthermore, involving CC instructors in a project that focuses on educational pedagogy may also lead to lasting changes on how they teach. In addition to student data, we are collecting information about instructor perceptions and classroom practices. Though still early in the data analysis, preliminary observations indicate these instructors are motivated to continue with the active learning they implemented as part of the project, with possible expansion of activities in time. To this end, we observed a shift in CC instructor attitudes towards student-centered teaching practices over the course of the year (unpublished observations).

Conclusion

The overarching aim of CAPER is to improve CC student outcomes using EBIPs, both by increasing implementation in CC classrooms and by generating research data to improve the efficacy of implementation. We hypothesize that involving CC instructors in educational research can achieve both of these goals, but this requires significant support. As more individuals complete their projects we hope that a supportive network of CC educational researchers will grow in spite of the challenges, and that they will assume leadership roles in organizations such as the Human Anatomy and Physiology Society. While the original CAPER project will finish in June 2020, we hope to expand the scope of this work by scaling up the project to include more instructors over a longer time period of two years for each cohort. Instructor recruitment will begin in Spring 2020 in preparation for a funding application in December. Interested individuals should contact Murray Jensen at msjensen@umn.edu.

Acknowledgement

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Murray Jensen teaches at the College of Biological Sciences at the University of Minnesota. Kerry Hull, Suzanne Hood, and Heather Lawford teach at Bishop's University in Sherbrooke, Canada. Kyla Ross teaches at Georgia Tech in Atlanta. Ron Gerrits teaches at the Milwaukee School of Engineering, and Betsy Ott teaches at Tyler Junior College in Texas. Murray, Kerry, Ron, Betsy and Kyla all teach courses related to human anatomy and physiology and are all long-time HAPS members. Suzanne and Heather are both phycologists and have helped the CAPER research team with topics related research design and data analysis.

Literature Cited

Bailey T, Smith Jaggers S, Jenkins D. 2015. Redesigning Americas Community Colleges: A Clearer Path to Student Success. Cambridge, MA: Harvard University Press.

Center for Community College Student Engagement. 2014. Contingent commitments: Bringing parttime faculty into focus (A special report from the Center for Community College Student Engagement). Austin, TX: The University of Texas at Austin, Program in Higher Education Leadership. http://www.ccsse.org/docs/PTF_Special_Report.pdf.

Center for Research on Lifelong STEM learning, Oregon State University. Evidence Based Instructional Practices. [accessed 2019 Nov 5]. https://stem.oregonstate.edu/esteme/ebips.

Connor KM, Kobak KA, Churchill LE, Katzelnick D, Davidson JR. 2001. Mini-SPIN: A brief screening assessment for generalized social anxiety disorder. *Depress Anxiety*. 14(2):137–140.

Fagen AP, Crouch CH, Mazur E. 2002. Peer Instruction: Results from a Range of Classrooms. *Phys Teach*. 40(4):206–209. doi:10.1119/1.1474140.

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Gerrits, R., (April 22, 2019). Community college anatomy and physiology education research program. (Blog Post) Retrieved from https://hapsblog.org/2019/04/22/community-college-anatomy-and-physiology-education-research-caper-program-promoting-change-in-classroom-pedagogy-to-benefit-students/

Field A. 2013. Discovering Statistics Using IBM SPSS Statistics. 4th ed. Los Angeles, CA: Sage Publications.

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci.* 111(23):8410. doi:10.1073/pnas.1319030111.

Human Anatomy and Physiology Society. 2019. HAPS Institute Previous Course Offerings - Human Anatomy and Physiology Society. [accessed 2019 Nov 5]. https://www.hapsweb.org/general/custom.asp?page=HAPSI_Previous.

Hood S, Barrickman N, Djerdjian N, Farr M, Magner S, Roychowdhury H, Gerrits R, Lawford H, Ott B, Ross K, Page O, Stowe S, Jensen M, Hull K. (2019a) "I like and prefer to work alone": social anxiety, academic self-efficacy, and students' perceptions of active learning. *Manuscript in preparation.*

Hood S, Barrickman N, Djerdjian N, Farr M, Magner S, Roychowdhury H, Gerrits R, Lawford H, Ott B, Ross K, Page O, Stowe S, Jensen M, Hull K. Some believe, not all achieve: the role of active learning practices in anxiety and academic self-efficacy in first generation college students. *Manuscript in preparation.*

Hull K, Lawford H, Hood S, Oliveira V, Murray M, Trempe M, Crooks J, Richardson M, Jensen M. 2019. Student anxiety and evaluation. CELT. 12:23–35. doi:10.22329/celt.v12i0.5409.

Jacobs S. 2016. The Use of Participatory Action Research within Education-Benefits to Stakeholders. *World J Educ*. 6(3):48.

Jenkins D, Fink J. 2016. Tracking Transfer: New Measures of Institutional and State Effectiveness in Helping Community College Students Attain Bachelor's Degrees. New York, NY: Community College Research Center, Teachers College, Columbia University.

McFarland J, Pape-Lindstrom P. 2016. The pipeline of physiology courses in community colleges: to university, medical school, and beyond. Adv Physiol Educ. 40(4):473–476. doi:10.1152/advan.00141.2016.

McIlroy D. 2000. An evaluation of the factor structure and predictive utility of a test anxiety scale with reference to students' past performance and personality indices. *British Journal of Educational Psychology*. 70(1):17–32. doi:10.1348/000709900157949.

Radwin D. 2017. 2015–16 National Postsecondary Student Aid Study (NPSAS:16) Student Financial Aid Estimates for 2015–16: First Look. https://nces.ed.gov/pubs2018/2018466.pdf.

Schinske JN, Balke VL, Bangera MG, Bonney KM, Brownell SE, Carter RS, Curran-Everett D, Dolan EL, Elliott SL, Fletcher L, et al. 2017. Broadening Participation in Biology Education Research: Engaging Community College Students and Faculty. *CBE Life Sci Educ*. 16(2):mr1. doi:10.1187/cbe.16-10-0289.

Snyder JJ, Sloane JD, Dunk RDP, Wiles JR. 2016. Peer-Led Team Learning Helps Minority Students Succeed. PLOS Biol. 14(3):e1002398. doi:10.1371/journal.pbio.1002398.

Stains M, Vickrey T. 2017. Fidelity of Implementation: An Overlooked Yet Critical Construct to Establish Effectiveness of Evidence-Based Instructional Practices. Allen D, editor. *CBE Life Sci Educ.* 16(1):rm1-11. doi:10.1187/cbe.16-03-0113.

Zeidenberg M. 2008. Community Colleges under Stress. Issues *Sci Technol*.:1–6.

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Effect of Word Bank Provision for Lab Practicals on Student Performance in Human Anatomy and Physiology I and II Courses

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Abstract
Providing word banks for human anatomy and physiology lab practicals is uncommon because instructors want to avoid cueing effects, but there is little published data on their effects on student performance. In the 2016-2017 academic year, word banks were not provided for students taking lab practicals in Anatomy and Physiology I and II while in 2017-2018 alphabetized word banks were provided. All other aspects of the courses remained the same. Student performance was significantly higher, though the effect size was small, on both lab practicals in Anatomy and Physiology I ($p<0.001$ for each) and the first lab practical in Anatomy and Physiology II ($p<0.001$). Scores on the 2nd lab practical in Anatomy and Physiology II and each lecture-lab course score were not affected by the provision of word banks. Results of this study will be useful when making decisions about providing word banks for lab practicals, weighting lab practicals for calculating grades, and responding to disability accommodation requests. https://doi.org/10.21692/haps.2020.004

Key words: lab practical, practical examination, word bank, anatomy, physiology, education

Introduction
This study was developed in response to multiple student requests for a word bank to be provided during laboratory practical examinations in human anatomy and physiology courses. These requests were always answered with a simple 'no' and some verbiage about the importance of assessing factual recall of anatomic identification without any hints or clues that would artificially inflate a student's score and bias the effectiveness of the assessment. These answers were typically met with a bit of shock as students may have been expecting a word bank on a recall examination (Glass et al., 2007). Students were apprehensive due to the high level of test anxiety in individuals who are pursuing the health professions and must complete multiple high-stakes exams to complete their programs (Schwartz et al., 2015). Yet, these answers were provided based on personal experiences as a student, graduate teaching assistant, and as an instructor rather than on experimental data. In other words, 'we've always tested like this in the lab, so this way must be the right way.'

In a typical lab practical (or "spotter") exam, the focus is often solely on knowledge recall (Choudhury et al., 2016; Smith and McManus, 2015; Yaqinuddin et al., 2013). The words "recall" and "identify" are active learning verbs frequently used at the first level of learning (Knowledge) in the anatomy-specific modification to Bloom's Taxonomy, the Blooming Anatomy Tool (BAT) (Thompson and O'Loughlin 2015). While questions at this level are straight forward often with answers stated verbatim (Thompson and O'Loughlin 2015), correctly identifying anatomical structures enables the student to advance higher levels of learning. The importance of "identify" as a desired learning outcome can be highlighted by the number of mentions of the word "identify" in the HAPS Anatomy Learning Outcomes (108 mentions, HAPS 2019a) and HAPS Anatomy and Physiology Learning Outcomes (104 mentions, HAPS 2019b). Correct identification as a learning goal is appropriate in courses such as Human Anatomy and Physiology I and II which are often prerequisites (i.e., the foundation) to further study.

To assess the "identify" learning outcome in students of human anatomy and physiology, the traditional laboratory practical, often called "spotter" exam, typically utilizes a series of labeled specimens (i.e., stations), each with questions relating to the specimen which the students must answer in the given time before moving on to the next specimen (Choudhury et al., 2016). Though formats for lab practicals vary across instructors and institutions, published examples of formats include the following procedures: students bring only a writing instrument into the examination (Krippendorf et al., 2008), are not allowed to touch the specimens (Choudhury et al., 2016; Sagoo et al., 2016), write a free-text response on an answer sheet (Shaibah and van der Vleuten 2013), are given a set time (60 seconds, Krippendorf et al., 2008; 90 seconds, Sagoo et al., 2016) to answer the question(s), and move to the next question station (often laid out in a circular stream; Inuwa et al., 2012) at the end of the interval.

A variation of the spotter exam that moves the level of learning assessed to the Comprehension level (i.e., the question is straight forward, but the answer requires more than a simple definition) in Thompson and O'Loughlin's (2015) BAT is the steeplechase examination. Here, the student is asked to identify a structure and then name an associated

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function or action (Smith and McManus, 2015). The objective structured practical examination (OSPE) pushes the level of learning assessed to the Application level of BAT (Thompson and O'Loughlin, 2015) by requiring that the student integrate anatomical knowledge with clinical skills (Choudhury et al., 2016; Yaqinuddin et al., 2013).

Schuwirth and van der Vleuten (2011) proposed the following four criteria to consider before deciding on an assessment format:

1. Is the assessment actually measuring what it is designed to measure (validity)?
2. Does the assessment produce consistent scores across different student cohorts (reliability)?
3. Does the assessment positively affect student learning and preparation (educational impact)?
4. Is the assessment a burden on instructional time (cost)?

The collective time required to develop questions for the practical, physically set up question stations, provide examination security by resetting the practical (e.g., switching questions between sections of students), marking answer sheets, and normalizing grading practices across instructors and teaching assistants is a cost to instructors. A cost to the institution is the functional limitation of the lab space during lab practical week as practical examinations are usually conducted on specimens in the anatomy laboratory (Inuwa et al., 2012).

Several investigators have developed protocols for lab practicals to minimize costs (typically of time and effort) while maintaining or enhancing validity, reliability, and educational impact of the lab practical. Manual grading of free text responses presents several costs and is prone to human error (e.g., correct answers may be marked wrong, incorrect answers may be given credit, total scores may be miscalculated; Krippendorf et al., 2008). Additionally, consistency in marking free text responses can be questioned (Choudhury et al., 2016), particularly across multiple instructors. Costs of time and inconsistency can be reduced by providing a choice of potential answers and using computer-graded assessments of lab practicals (Gentile et al., 2019), but they must be balanced by verifying that the assessment is valid. In other words, does providing a choice of potential answers for lab practical examinations accurately measure "correctly identify ___" learning outcomes, or are student scores distorted from the cueing effects (Damjanov et al., 1995; Fenderson et al., 1997) available from the list of choices?

Extended matching tests, where students select the best answer to a question from a list of 20 options, each of which may be used once, more than once, or not at all (Fenderson et al., 1997) are one possible alternative but there are far more than 20 options for a typical lab practical. Increasing the length of the options to several hundred or more alphabetized items creates an uncued exam (Fenderson et al., 1997). Krippendorf et al. (2008) created an uncued lab practical for first-year medical students by:

1. Providing students at the beginning of the course with lists of structures that would be on the lab practicals.
2. Providing students with a numbered, alphabetized list that they could refer to during the lab practicals.
3. Having students write the number of their selected item on their answer sheets.
4. Using an optical scanner to automatically grade the practical.

Krippendorf et al. (2008) found this method greatly reduced faculty grading time, reduced grading errors, and provided faster performance feedback for students without changing overall student performance. However, no student scores were reported nor were the results of any statistical tests performed (Krippendorf et al., 2008).

In a different study, Shaibah and van der Vleuten (2013) tested the performance of 100 gross anatomy students on a steeplechase lab practical in which answers could be provided via free text response or multiple-choice questions, each with five options. Average performance of students was significantly higher when multiple choice questions were used (91.17% $\pm$ 10.58 SD to 87.17% $\pm$10.84 SD, $p<0.001$). Shaibah and van der Vleuten (2013) raise the discrepancy between their results and those of Krippendorf et al. (2008) and suggest that the difference in results could be due to one of two reasons: 1. the populations used in the Krippendorf study were independent; or 2. cueing effects were removed by using a long list of about 300 options instead of using five options. Yet, the two studies cannot be compared because there are no data reported in Krippendorf et al. (2008).

Since there are no reported data supporting the presence or absence of the effect of word banks on student performance on lab practical examinations, there is no real mechanism to defend the position that providing a word bank fundamentally alters the nature of the lab practical examination by providing visual cues that provide prompts or hints that may artificially inflate a student's score. Thus, this study will test the null

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hypothesis that providing word banks for lab practical examinations has no significant positive or negative effect on student performance on the following:

1. Lab practical examination #1.
2. Lab practical examination #2.
3. Four-credit lecture-lab courses in which lab practical examinations are part of the laboratory curriculum.
4. Hypothetical one-credit lab only courses.

The latter null hypothesis was tested because:

1. Course numbering systems for Anatomy and Physiology lecture and lab courses are unique to the academic institution.
2. The effect of providing word banks for lab practicals may be more impactful for instructors teaching one-credit laboratory courses in which 50% of a student's grade may be determined by their scores on lab practicals.

Materials and Methods

General Course Description and Student Profile

At the University of Mississippi, Human Anatomy and Physiology I (hereafter referred to as A&P I) and Human Anatomy and Physiology II (hereafter referred to as A&P II) are general education, non-majors service courses offered through the Department of Biology. Other than admission to the university, there are no prerequisites to enroll in A&P I. Admission requirements did not change during this study. Students must earn a grade of C or better in A&P I to enroll in A&P II. Both courses are four-credit, lecture-lab courses in which the student receives a single letter grade for the course.

The content included in A&P I begins with an introduction to the human body and a review of chemistry and cells. The course continues with the study of tissues and the integumentary, skeletal, muscular, and nervous systems (excluding the special senses). In A&P II content begins with the special senses and continues with the endocrine, cardiovascular, immune, respiratory, digestive, urinary, and reproductive systems.

During a regular academic year, A&P I is only offered in the fall semesters, and A&P II is only offered in the spring semesters. Both A&P I and II are offered during summer sessions, but data from summer session performance is not included in the study.

The only difference in the administration of the A&P I and II courses between the 2016-2017 and 2017-2018 academic years was the provision of word banks during lab practicals in the 2017-2018 academic year.

For each course, there was a single lecture section meeting at 8am on Mondays, Wednesdays, and Fridays in the same auditorium (capacity of 394 students) at the University of Mississippi with the same instructor of record (Britson). The same editions of the lecture textbook (Amerman, 2016), lab manual (Whiting, 2016), and online resources (Pearson Education's Mastering™ A&P) were used throughout both academic years as was the university's course management system, BlackBoard™. Laboratory sections were capped at 30 students per section, staffed by two teaching assistants (TAs), held in the same laboratory room at the University of Mississippi, and met for two hours once per week beginning in the second week of the semester.

In A&P I there were 13 lab sections that met beginning at 11am on Tuesdays, Wednesdays, and Thursdays (four sections per day) with one section beginning at 11am on Fridays. In A&P II there were nine lab sections that met beginning at 11am on Tuesdays, and Wednesdays (three sections per day), 11am on Thursdays (two sections per day), and 1 section beginning at 11am on Fridays. There were nine TAs for A&P I in 2016 and 13 TAs in 2017 with four of the these being TAs in both years. There were nine TAs for A&P II in both 2017 and 2018 with four of the these being TAs in both years. All TAs were undergraduates that successfully passed both A&P I and A&P II with scores of 87% or higher and were selected through an identification and interview process (Hopp et al., 2019).

Additionally, there were two supplemental instruction (SI) leaders each semester that held a minimum of six (total), one-hour, peer-led study sessions each week of the course. Each SI leader served for both fall and spring semester within an academic year, and one of the SI leaders served in this role for both academic years. All SI leaders were undergraduates that successfully passed both A&P I and A&P II with scores of 80% or higher and were selected through an identification and interview process. Prior to beginning their time as an SI leader, they also underwent several training sessions administered through the university's Center for Excellence in Teaching and Learning.

For each course, grades were calculated and weighted from the following assessments: lecture exams (five total, 60% of grade), lecture quizzes (five total, 5% of grade), lab quizzes (ten total, 8% of grade), formative in-lab assessments (11 total, 7% of grade), lab practicals (two total, 10% of grade), and online homework (four to six per week, 10% of grade). Lecture exams were 50 multiple choice questions each; lecture quizzes were five multiple choice questions each; lab quizzes were ten questions based on the pre-lab readings and consisted of multiple choice, fill in the blank, or true-false questions; and in-lab assessments were short activities,

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experiments, or round-robin quizzes. The round-robin quizzes and lab practicals will be described later in this section. Online homework consisted of 10-15 multiple choice questions per assessment (from both lecture and laboratory content) that were "open-book" assessments, but questions were randomly pulled from a pool of 40-50 questions and students were only allowed one attempt on the assessment. Except for the online homework, all assessments were completed in a face-to-face classroom setting. Each course was structured such that there was no more than one "high-stakes" assessment (e.g., lecture exam, lecture quiz, or lab practical) per week. Relative weights for each category of assessment were determined based on assessment difficulty and relative contribution of the lecture (75%) and laboratory (25%) contact hours.

The student group in 2016-2017 (word banks not provided) was comprised of 302 students enrolled in A&P I for the fall semester and 231 students enrolled in A&P II for the spring semester. The student group in 2017-2018 (word banks provided) was comprised of 318 students enrolled in A&P I for the fall semester and 200 students enrolled in A&P II for the spring semester. Declared majors of students enrolled in the courses were exercise science (30%), allied health including nursing and nutrition(28%), other science majors (e.g., biology and pharmacy, 28%), and other liberal arts or applied science majors (14%).

The demographic breakdown by major per year has been consistent since these data were collected beginning in 2011. Prior research on students enrolled in these two courses revealed that most students were interested in careers in nursing, physical therapy, occupational therapy, physician assistant, or dietetics (Hillhouse and Britson, 2018; O'Connor and Britson, 2017). Almost all students were in their 2nd or 3rd year of undergraduate education, were traditional college students between the ages of 18 and 23 years, and varied in race and gender. This study (Protocol #19x-003) was reviewed by The University of Mississippi's Institutional Review Board (IRB) and was approved as Exempt under 45 CFR 46.101(b) (#1 and 4).

Laboratory Content and Lab Practical Format

A weekly list of specific topics, the format of the in-class lab assessment, and the number of items on the weekly "Need to Know" list for A&P I and A&P II during both academic years is presented in Table 1. The Need to Know lists were posted on BlackBoard™ and were always available to the students. The in-class lab assessments were the only assessments in the course that were completed by a small group of three to four students (all other assessments were completed individually) and consisted of a variety of short activities (e.g., concept mapping, sensory receptor density, etc.), data acquisition system experiments (e.g., electromyography, blood pressure, etc.), and round robin quizzes. That latter of which were formative assessments designed to prepare students for the lab practicals and were very popular with the students.

To prepare for the round robin quizzes each group of students (a maximum of four per workstation, eight total workstations) were given a short selection of six to eight items from the weekly Need to Know list. They were tasked with using the models and specimens available at their workstation to create two identification questions (e.g., identify this tissue, identify this bone, etc.) for the round robin quiz. With all groups contributing, a short quiz of 16 identification questions was produced. The round robin quiz began when there was 15 minutes remaining in the lab session. Each group of students could bring the answer sheet and one copy of the Need to Know list with them as they walked around to each workstation, allowed two minutes at each workstation, conferred within their group, and answered the available questions. At the end of the quiz, each group submitted their answers and copy of the Need to Know list.

Lab practicals were administered twice each semester during weeks seven and 14 of a 15-week term. A word bank was prepared for each lab practical by combining and alphabetizing all the items on the Need to Know lists preceding each lab practical. Items were alphabetized to prevent cueing effects (Damjanov et al.,1995; Fenderson et al., 1997) that may have been present if items were grouped by week or body system. A small subsample of ten items from each word bank are presented in Table 2.

Each lab practical consisted of 50 questions that were presented at 16 "stations" throughout the laboratory classroom, with three to four questions per station. The number of questions per topic was determined by identifying the total number of items from the combined Need to Know list, dividing the number of each week's Need to Know items by the total, and then multiplying the result by 50. For example, there were 341 total items for the second lab practical of A&P I. There were 32 items for week nin e content which represented 9.4% of the total number of items. After multiplication and rounding, five of the 50 questions on the second lab practical were devoted to muscle tissue and an introduction to the muscular system.

Week eight had a much larger percentage of the total content (109 items representing 31.9%) and 16 questions on the lab practical were devoted to the appendicular skeleton and joints. This proportional division of the 50 questions was performed to reflect the relative difficulty and amount of time students would spend studying each area of content in preparation for the lab practicals. This proportional division of questions is similar to the matrix method used by Smith and McManus (2015) to determine the number of questions per content as based on the number of course hours per topic.

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	A&P I			A&P II		
Week	**Topic**	**In-class Assessment**	**NTK list items**	**Topic**	**In-class Assessment**	**NTK list items**
1	no labs			no labs		
2	Intro. to A&P; Intro to Organ Systems	Study strategies worksheet	112	General Senses	Sensory receptor density	17
3	The Microscope; The Cell	Memory matrix	33	Special Senses #1	Round robin quiz	61
4	Histology	Concept mapping	39	Special Senses #2; Endocrine System	Diabetes experiment	34
5	Integumentary System; Intro to Skeletal System	Round robin quiz	70	Blood	Blood assays	15
6	Axial Skeleton	Round robin quiz	90	Anatomy and Physiology of the Heart	ECG experiment	42
7	Lab Practical #1			Lab Practical #1		
8	Appendicular Skeleton; Joints	Round robin quiz	109	Blood Pressure; Blood Vessels #1	BP experiment	21
9	Intro to Muscular System: Muscle Tissue	Intro to data acquisition equipment	32	Blood Vessels #2; Lymphatic System	Round robin quiz	68
10	Muscular System	EMG experiment	71	Anatomy of Respiratory System	Round robin quiz	47
11	Intro to Nervous System	Round robin quiz	35	Physiology of Resp. System; Anatomy of Digestive System	Lung volumes experiment	69
12	Central Nervous System: Brain and Spinal Cord	Round robin quiz	53	Anatomy and Physiology of the Urinary System	Round robin quiz	26
13	Peripheral Nervous System: Nerves	Reflex experiment	41	Reproductive Systems; Development	Round robin quiz	68
14	Lab Practical #2			Lab Practical #2		

Table 1. *Weekly list of specific topics, the format of the in-class lab assessment, and the number of items on the weekly "Need to Know" list for A&P I and A&P II during the 2016-2017 and 2017-2018 academic years.*

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All lab practical questions were developed by the instructor of record (Britson), and the physical question stations were prepared by the laboratory TAs. The development of questions included preparing for "resets" of answers each day as a different answer key was used for each day's lab section. Resetting a lab practical consisted of moving a label, switching a microscope slide, etc. For example, on the first day of the lab practical, the question may be 'Identify this sublayer' with the answer of 'stratum lucidum'. On the second day of the lab practical, the answer may be 'stratum basale', on the third day, the answer may be 'stratum spinosum', and so on. Over the course of four days of testing, the majority of the items were used as an answer item.

The 30 students enrolled in each lab section were divided into two groups to take the lab practical during the first or second hour of the lab session. Upon entering the lab, they were given a numbered answer sheet with the word bank attached. Students were given approximately three minutes per station and only one student was allowed per station. At the end of a full rotation, students were given five minutes to revisit any station they wished before submitting their answer sheet with the word bank still attached. Two TAs supervised testing at all times. A separate extended testing session was provided for students with approved testing accommodations.

Before entering scores in the Learning Management System, all TAs met with the instructor or record (Britson) for grade normalization, a procedure which has been used since 2014 in maintain reliability and validity of grading procedures and scores across sections and years. During this meeting, the instructor of record made all final decisions about answers that would receive full credit (two points), partial credit (one point), or no credit (zero points). As an example, if the correct answer was "descending colon", an answer of ascending colon would receive partial credit. All students were held to the same policy on spelling (i.e., two incorrect letters allowed as long as the meaning of the term is not affected and 0.5 points off for each additional incorrect letter). Students with approved spelling accommodations are given an additional incorrect letter (i.e., three letters) before the deductions begin.

A&P I (fall semester)		A&P II (spring semester)	
LP1	**LP2**	**LP1**	**LP2**
Cardiac muscle	Basal nuclei	Chordae tendineae	Capillary
Cardiovascular	Biceps brachii	Choroid	Capsular space
Carotid canal	Biceps femoris	Ciliary body	Cardia of stomach
Carpal	Bipolar neuron	Circumflex artery	Cardiac notch
Central canal	Brachial plexus	Cochlea	Carina
Centriole	Brachialis	Cochlear branch	Cartilaginous rings
Centrosome	Brachioradialis	Cone	Cecum
Cephalic	Brain	Cornea	Central vein of liver
Cervical	Brainstem	Coronary sinus	Cephalic vein
Cervical curvature	Buccinator	Delta cell	Cervix of uterus

Table 2. *Subsample of 10 items from the combined Need to Know lists (i.e., word banks) provided for each lab practical (LP1 and LP2) in the 2017-2018 academic year in which word banks were provided. All items in each work bank were alphabetized, printed, and stapled to the answer sheet given to each student. The subsample was selected from approximately the same location (i.e., starting with the 30th item) in each list.*

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Analytical Methods

For A&P I and II a one-way analysis of variance (ANOVA) with the level of significance set at alpha=0.05 was used to test the effect of providing word banks on student performance on the first and second lab practicals, the overall (4-credit, lecture and lab) course score, and a hypothetical lab-only course score. Relative contributions of online homework, lab quizzes, and formative in-lab assessments were maintained. For example, in a four-credit lecture-lab course lab practicals (two total) were weighted as 10% of the entire course grade but were 28.5% of the hypothetical lab-only course score. Lab quizzes (ten total), formative in-lab assessments (11 total), and lab-related only online homework assessments (22 total) were weighted as 22.9%, 20%, and 28.5% of the hypothetical lab-only course score, respectively. Effect sizes were calculated using Cohen's d statistic (McLeod 2019) for each one-way analysis. All analyses were performed using SPSS statistical package, Version 22 (SPSS, Chicago, IL) licensed to the University of Mississippi.

Results

Student performance on both lab practicals was significantly higher when word banks were provided in A&P I [(F = 11.313; df = 1,619; p = 0.001 for Lab Practical 1), (F = 16.013; df =1,619; p < 0.001 for Lab Practical 2) (Figure 1)]. Overall numerical performance of students in a four-credit, lecture-lab A&P I course was not significantly different when word banks were provided for lab practicals (F = 3.601; df =1,619; p = 0.058; Fig. 1). For a hypothetical, one-credit lab-only A&P I course, student performance was significantly higher when word banks were provided (F = 8.214; df =1,619; p = 0.004; Figure 1). Effect sizes (d) for A&P I data were 0.268 for the first lab practical, 0.317 for the second lab practical, -0.152 for the four-credit, lecture-lab course score, and 0.228 for the hypothetical, one-credit lab-only course score. A Cohen's d value of 1 would indicate that means differ by 1 standard devation, a d of 2 indicates that the mean differ by 2 standard deviations, etc. (McLeod 2019). A d of 0.1 to 0.3 is considered a small effect size, a value of 0.3 to 0.5 a medium effect, and value above 0.5 a large effect (Cohen 1988).

In A&P II, student performance on the first lab practical was significantly higher (F = 35.194; df = 1,430; p < 0.001; Figure 2) when word banks were provided but was not significantly different for the second lab practical (F = 2.344; df =1,430; p = 0.126; Figure 2). Overall numerical performance of students in a four-credit, lecture-lab A&P II course was not significantly different when word banks were provided for lab practicals (F = 0.280; df =1,430; p = 0.597; Figure 2). For a hypothetical, one-credit lab-only A&P II course, student performance was significantly

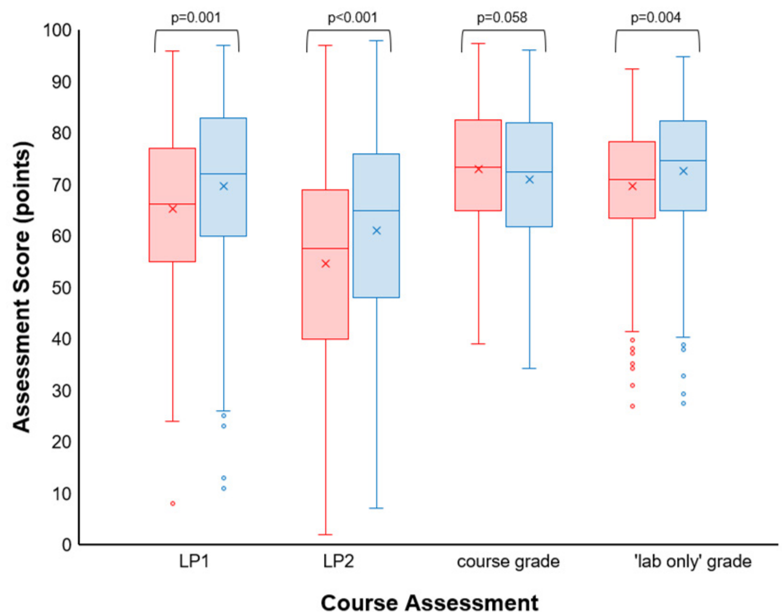

Figure 1. *Human Anatomy & Physiology I scores at the University of Mississippi for Fall 2016 (red boxes, no word banks provided with lab practicals; n=302) and Fall 2017 (blue boxes, word banks provided; n=318). Scores for two lab practicals (LP1, LP2), numerical scores for a 4-credit lecture/lab course, and a hypothetical 1-credit lab only course are depicted. Within each box the assessment mean is represented by "x", the middle line is the assessment median, the bottom and top lines of the box represent the 1st and 3rd quartiles respectively, and the top and bottom bars represent the maximum and minimum values respectively. Individual data points (open circles) greater than 1.5 times the interquartile range represent outliers beyond the maximum or minimum values. ANOVA test results for between-subject effects are shown with exact p-values.*

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higher when word banks were provided (F = 17.771; df =1,430; p < 0.001; Figure 2). Effect sizes (d) for A&P II data were 0.551 for the first lab practical, 0.147 for the second lab practical, -0.051 for the four-credit, lecture-lab course score, and 0.399 for the hypothetical, one-credit lab-only course score.

Discussion

In this paper, the impact of providing word banks with lab practicals on student performance and course outcomes with a study that provides multiple, useful outcomes was examined. In A&P I, student scores were significantly higher on both lab practicals in the semester where word banks were provided, but the impact of large standard deviations relative to actual differences between the means (i.e., a small effect size) indicates that statistical significance was due to a large sample size rather than true, artificial inflation of scores.

In terms of classroom significance, as compared to statistical significance, the difference in means between the semester where word banks were provided and the semester where word banks were not provided is no more than two questions (out of 50) for the first lab practical and 3.5 questions for the second lab practical. For the first lab practical in A&P II, student scores were significantly higher in the semester where word banks were provided, but the effect size was stronger. The difference in mean scores was the point value of 3.5 questions and similar to student performance for the second lab practical in A&P I, but smaller standard deviations within the sample led to the increased effect size.

The decrease in magnitude of the standard deviations is likely a result of A&P II students having met the prerequisite of successfully passing A&P I with a grade of "C" or better. This prerequisite aligns with the HAPS (2019c) suggested, required prerequisite for A&P II courses. Student scores for the second lab practical in A&P II were not statistically different and represented a classroom difference of one more question correctly answered when word banks were provided. Throughout the 2017-2018 academic year teaching assistants communicated personal observations that students were making fewer spelling errors as compared to the 2016-2017 academic year, but students continued to leave some questions unanswered.

Shaibah and van der Vleuten (2013) observed significantly higher scores for students taking a lab practical with multiple-choice questions but questioned the impact of their results when compared to those of Krippendorf et al. (2008). Shaibah and van der Vleuten (2013) incorrectly inferred that there were no statistically significant

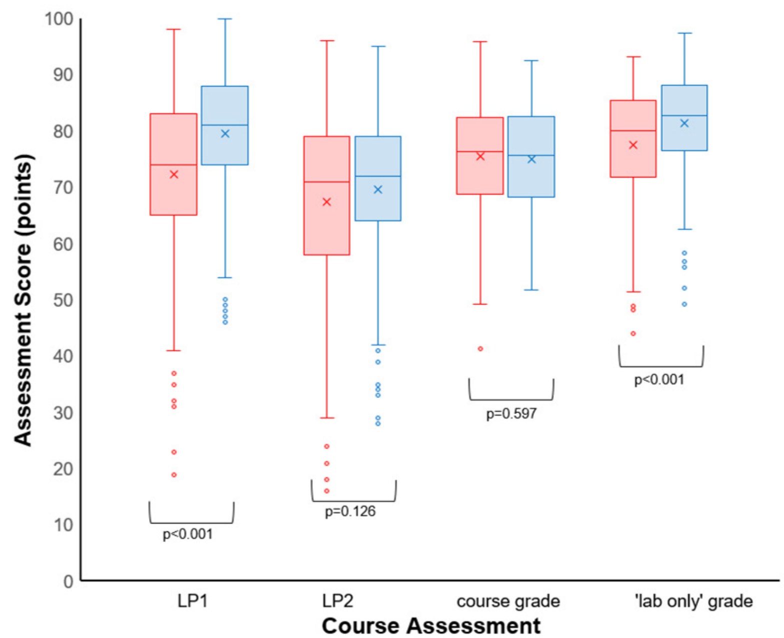

Figure 2. *Human Anatomy & Physiology II scores at the University of Mississippi for Spring 2017 (red boxes, no word banks provided with lab practicals; n=231) and Spring 2018 (blue boxes, word banks provided; n=200). Scores for two lab practicals (LP1, LP2), numerical scores for a 4-credit lecture/lab course, and a hypothetical 1-credit lab only course are depicted. Within each box the assessment mean is represented by "x", the middle line is the assessment median, the bottom and top lines of the box represent the 1st and 3rd quartiles respectively, and the top and bottom bars represent the maximum and minimum values respectively. Individual data points (open circles) greater than 1.5 times the interquartile range represent outliers beyond the maximum or minimum values. ANOVA test results for between-subject effects are shown with exact p-values.*

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differences in Krippendorf et al.'s (2008) paper. However, only observations that student scores were not "noticeably different" when students were given a list of terms during a lab practical rather than student performance data were reported in Krippendorf et al. (2008). With a sample size of 100 students taking a single lab practical successively in two different formats, Shaibah and van der Vleuten (2013) document a four-point increase in mean performance. While they did not report effect size, means and standard deviations for recall questions (24 total) reported in Table 2 of Shaibah and van der Vleuten (2013) can be used to estimate a small-to-moderate (McLeod 2019) effect size of 0.38. In their study, the difference in student performance is three more correctly answered questions in the multiple-choice lab practical.

Across the multiple assessments of an entire course, the impact of any one or two assessments was low. A philosophy central to the relative weightings of assessment categories for the courses in this study is 'no one assessment can make or break' a student's score for the course. The lack of significant differences in student performance in A&P I and II courses where words banks were not provided for lab practicals (2016-2017 academic year) and where word banks were provided (2017-2018 academic year) is reflective of the number and relative weights of each type of assessment for calculation of a student's course performance.

This study is not unique in analyzing student performance across multiple cohorts of students and different formats of lab practicals over entire courses. Choudhury et al. (2016) and Smith and McManus (2014) studied lab practical performance from six, year-long cohorts of optometry students and five, year-long cohorts of Bachelor of Medicine students, respectively in the United Kingdom. The present study, however, focuses on introductory, human anatomy and physiology students often in their first or second year of post-secondary education rather than upper division or professional school students.

To compare student performance in hypothetical, one-credit laboratory courses, the relative weightings of online homework supporting laboratory learning outcomes, lab quizzes, formative in-lab activities, and lab practicals were maintained for calculation of a lab course score. These hypothetical, one-credit laboratory course scores were significantly higher for A&P I and II when word banks were provided for students taking lab practicals. Though the effect size is small to medium in each comparison, a small numerical difference can have a larger, relative impact on a student's letter grade. In the calculation of a student's (or applicant's) grade point average, however, the "weighting" of a course grade is reflected in the credit hours earned. Thus, the effect of providing word banks for lab practicals in a one-credit course, though positively significant, would be unlikely to carry over to statistically significant effects, and large effect sizes, on the student's semester or overall GPA. A thorough study of the effects of relative weighting of assessments on student performance in human A&P courses is warranted, however, as McDonald et al. (2016) found that increasing the grade weighting of lab practicals, while maintaining all other aspects of curriculum design, in a human anatomy course led to improved scores on the lab practical assessments, the number of students passing the practical assessments, and performance on subsequent assessments in a four year study.

Conclusions

Laboratory practical examinations provide instructors with the ability to assess students on their understanding of three-dimensional spatial relations of anatomical structures to others and their ability to differentiate between similar structures (Smith and McManus 2015). Despite the costs of time and resources to set up, deliver, and grade laboratory practicals (Schuwirth and van der Vleuten 2011), the educational value they provide motivates instructors to develop innovations that minimize costs.

Alternatives to the spotter format such as the steeplechase (Smith and McManus 2015) and objective-structured practical examination (Choudhury et al., 2016; Yaqinuddin et al., 2013) increase the educational impact of the lab practical assessment. Modifications to the set-up, delivery (such as the provision of word banks), and grading minimize costs but these reductions must not be at the expense of the validity and reliability of the assessment. This study has shown providing word banks for students taking lab practicals in human A&P I and II courses (1) increases student performance on the practicals though the effect size is small and (2) the overall score in a four-credit, lecture-lab course is unaffected. For the latter, careful consideration of how assessments are weighted for the calculation of a student's overall score is critical in judging the effect of providing word banks.

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Literature Cited

Amerman EC. 2016. Human Anatomy & Physiology, 1st Ed. Pearson Education, Inc.

Choudhury B, Gouldsborough I, and Shaw FL. 2016. The intelligent anatomy spotter: A new approach to incorporate higher levels of Bloom's taxonomy. *Anat Sci Ed* 9:440-445.

Cohen J. 1988. Statistical Power Analysis for the Behavioral Sciences, 2nd Ed. Routledge.

Damjanov I, Fenderson BA, Veloski JJ, and Rubin E. 1995. Testing of medical students with open-ended, uncued questions. *Hum Pathol* 26:362-365.

Fenderson BA, Damjanov I, Robeson MR, Veloski JJ, and Rubin E. 1997. The virtues of extended matching and uncued tests as alternatives to multiple choice questions. *Hum Pathol* 28:526-532.

Gentile M, Melovitz-Vasan C, Huff S and Vasan N. 2019. The utilization of ExamSoft-iPad technology in administering and grading anatomy practical examinations. *Med Sci. Educ* 29:831-840. https://doi.org/10.1007/s40670-019-00750-0

Glass LA, Clause CB, and Kreiner DS. 2007. Effect of test-expectancy and word bank availability on test performance. *College Student Journal* 41(2).

HAPS. 2019a. Human Anatomy and Physiology Society, Anatomy Learning Outcomes, Revised Fall 2019.

HAPS 2019b. Human Anatomy and Physiology Society, Anatomy and Physiology Learning Outcomes, Revised Fall 2019.

HAPS 2019c. Human Anatomy and Physiology Society, Course Guidelines for Undergraduate Instruction in Human Anatomy and Physiology. https://www.hapsweb.org/page/course_guidelines (accessed 8 February 2020).

Hillhouse KC and Britson CA. 2018. Bring your own device initiative to improve engagement and performance in Human Anatomy and Physiology I and II laboratories. *HAPS Educator* 22(1):40-49. https://doi:10.21692/haps.2018.004

Hopp R, Britson C, Mukhopadhyay S, Goldina A, Chapman M, and Nielsen M. 2019. Teaching assistants in human anatomy and physiology: Their prevalence, recruitment strategies, funding, retention, and training. *HAPS Educator* 23 (2): 367-84. https://doi.org/10.21692/haps.2019.015

Inuwa IM, Taranikanti V, Al-Rawahy M, and Habbal O. 2012. Anatomy practical examinations: How does student performance on computerized evaluation compare with the traditional format? *Anat Sci Ed* 5:27-32.

Krippendorf BB, Bolender DL, and Kolesari GL. 2008. Computerized grading of anatomy laboratory practical examinations. *Anat Sci Ed* 1:220-223.

McDonald AC, Chan SP and Schuijers JA. 2016. Practical session assessments in human anatomy: Weightings and performance. *Anat Sci Ed* 9:330–336.

McLeod SA. 2019 (July 10). *What does effect size tell you? Simply Psychology*. https://www.simplypsychology.org/effect-size.html

O'Connor AE and Britson CA. 2017. Analysis of an arthritis simulation activity developed as a laboratory exercise for allied health students. *HAPS Educator* 21: 30-38. https://doi:10.21692/haps.2017.005

Sagoo MG, Smith CF, and Gosden E. 2016. Assessment of anatomical knowledge by practical examinations: The effect of question design on student performance. *Anat Sci Educ* 9:446–452.

Schuwirth LW and van der Vleuten CP. 2011. General overview of the theories used in assessment: AMEE Guide No. 57. *Med Teach* 33:783–797.

Schwartz SM, Evans C, and Agur, AMR. 2015. Comparison of physical therapy anatomy performance and anxiety scores in timed and untimed practical tests. *Anat Sci Educ* 8:518-524.

Shaibah HS and van der Vleuten CPM. 2013. The validity of multiple choice practical examinations as an alternative to traditional free response examination formats in gross anatomy. *Anat Sci Educ* 6:149–156.

Smith CF and McManus B. 2015. The integrated anatomy practical paper: A robust assessment method for anatomy education today. *Anat Sci Educ* 8:63–73.

Thompson AR and O'Loughlin VD. 2015. The Blooming Anatomy Tool (BAT): A discipline-specific rubric for utilizing Bloom's Taxonomy in the design and evaluation of assessments in the anatomical sciences. *Anat Sci Educ* 8:493–501.

Whiting CC. 2016. Human Anatomy & Physiology Laboratory Manual: Making Connections, Main Version, 1st Ed. Pearson Education, Inc.

Yaqinuddin A, Zafar M, Ikram MF, Ganguly P. 2013. What is an objective structured practical examination in anatomy? *Anat Sci Educ* 6:125–133.

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Optimal Dosing of the Anesthetic Tricaine Methanesulfonate (MS222) to Ensure Muscle Viability in *Xenopus leavis* Frogs: A Protocol Project

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Abstract
Tricaine Methanesulfonate (MS222) is frequently used as an anesthetic on frogs prior to euthanasia. However, the optimal dose to maintain muscle viability is not currently known. *Xenopus leavis* frogs were immersed in solutions of MS222 (0.05% w/v dose up to, 0.30% w/v dose) prior to achieving a humane endpoint. The gastrocnemius muscle was dissected and positioned on a force transducer and stimulated using an external probe. Graded muscle responses were analyzed for minimum excitation voltage and maximal tension force. Unpaired T-Test results showed statistically significant differences in minimal excitation voltage (21mv + 8 mv vs. 49mv + 27 mv, P=0.000627) between the low dose and high dose groups respectively. Maximal tension force was scaled relative to gastrocnemius muscle mass and mass$^{2/3}$ and found to be statistically significant. Marked changes in muscle viability were most notable at doses above 0.20%. MS222 doses of 0.15% with immersion times of five minutes appear to be adequate for reaching AVMA anesthetic guidelines prior to euthanasia, while maintaining muscle viability. https://doi.org/10.21692/haps.2020.002

Introduction

The aim of this protocol project is to determine the lowest dose of MS222 necessary to achieve the appropriate humane endpoint according to American Veterinary Medical Association (AVMA) 2013 guidelines while maintaining maximal skeletal muscle response after euthanasia (AVMA 2013). A secondary aim when identifying the lowest dose necessary is to minimize student exposure to such agents in a teaching lab.

Despite the decline in the use of animals and live tissue in teaching labs since the 1980's, frog muscle continues to be used when teaching the complex characteristics of nerve, skeletal and cardiac muscle (Franco 2013; Raanan 2005). Reasons for this decline include staff training limitations, reductions in lab budgets, cultural sentiment, and the replacement of live tissue with robust computer simulations (Franco 2013; Raanan 2005). While computer simulations may improve written test scores comparable to students who also performed animal dissections, there was a marked difference in practical skills when evaluated in a high school AP environment (Cross and Cross 2004). Moreover, it has been suggested that live tissue labs contribute a more complex and rich learning environment for students to learn basic physiological concepts (Shore et al. 2013). In a recent study, 55% of 2nd year and 63.2% of 3rd year undergraduate medical students agreed or strongly agreed that physiology experiments using amphibians were important at the undergraduate level and that facts are learned better using a combination of live experiments in addition to computer simulations (87.4% and 72% respectively) (Shore et al. 2013).

Moore and Noonan (2010) state that animal tissue labs can provide an increased sense of learner responsibility, longer-term psychomotor competency, and the ability to enhance functional relationships. Therefore, these studies support the notion that labs utilizing animal tissues can enhance the learner's ability regardless of age, grade level, or experience to understand and gain competency with physiological systems and the complex functional relationships between systems.

For those conducting live tissue labs, the guidelines for euthanizing frogs have changed. It was once proper to immerse frogs or other amphibians in an ice bath rendering the frog dormant prior to pithing (euthanizing) and subsequent dissection (Lillywhite et al. 2016). Updated AVMA guidelines forbid using ice bath immersion as a sole anesthetizing agent and instead require some other agent such as Tricaine Methanesulfonate (MS222) prior to achieving a humane endpoint (AVMA 2013). MS222 is an amino amide class agent preferentially blocking voltage-gated sodium channels on excitable tissues such as nerve, skeletal and cardiac muscle (Attili and Hughes 2014). It induces muscle paralysis and loss of consciousness by crossing the Blood-brain barrier in fish and amphibians and is fully reversible at lower doses with a half-life of 1.5 – 4.0 hours (Attili and Hughes 2014; Beckman 2016; Allen 1986). This drug is preferred during veterinary procedures due to its hydrophilic properties rendering it soluble in water, therefore fully anesthetizing fish and amphibians by depressing motor functions and inducing analgesia through absorption (Beckman 2016; Ramlochansingh et al. 2014). However, exposing

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undergraduate students to high or chronic doses of MS222 despite proper protective equipment (PPE) may continue to pose hazards of retinal toxicity (Bernstein et al.1997). Furthermore, toxicological properties of MS222 have not been fully investigated and are of undetermined acute toxicity (Western Chemical, Inc. 2015).

According to AVMA Guidelines, concentrations of 0.5g/L (.05% w/v) to 5g/L (.5% w/v) of MS222 and immersion times up to one hour are recommended depending on the age, size, and life history of the animal species (AVMA 2013). These veterinary guidelines were established with the expectation that the drug would be eliminated from the animal's system over a 1-2 hour period permitting a full return to its prior activity and function (Mitchel 2009). However, few guidelines are available to determine an anesthetizing dose while maintaining the viability of excitable tissue. A study by Lalonde-Robert et al. (2012) determined that anesthetic doses as low as 1-2g/L (0.1%w/v - 0.2%w/v) do not affect heart function in amphibians but may influence respiratory function. While previous research shows no loss of evoked muscle response in zebrafish after immersion in MS222, there is a growing body of evidence that higher doses (>2g/L) and longer immersion times (>20 minutes) may have an effect on nerve and muscle activity (Attili and Hughes 2014; Medler 2019).

A recent study explained the challenges that MS222 poses on excitable tissue response when used as an anesthetic on frogs in a teaching lab (Medler 2019). Medler (2019) suggests that teaching faculty who still perform these types of labs should experiment with various doses and immersion times to find the optimal dose that will enable their experiments to work. Unpublished survey data results expose the variability in protocols instructors will use to anesthetize amphibians before dissection (Zubek 2019). Instructors report using MS222 doses ranging from 1g/L (0.1% w/v) up to, 5 g/L (0.5%w/v) with immersion times ranging from five minutes to greater than one hour. Recovery times prior to tissue dissection and subsequent data collection also varied. Some instructors used the tissue specimens immediately after removal while some waited up to 24 hours after removal.

Anecdotal evidence in our teaching lab at Michigan State University consistently rendered failed experiments with concentrations greater than 2.5g/L (0.25 %w/v) despite immersion times of five to ten minutes. Due to a paucity of evidence, MSU Institutional Animal Care and Use Committee (IACUC) initially recommended a dose of 3 g/L (0.3%w/c) and at least ten minutes of immersion time. There were no practical guidelines available to support a concentration that would maintain muscle viability and reduce student exposure. In addition, long immersion times coupled with long recovery times may not be feasible in a teaching lab running multiple sections with limited technician assistance.

Methods

Animals.

Juvenile *Xenopus leavis* frogs with an average body mass of 22.2 grams (13g-37.3g) were purchased from Nasco (Ft. Atkinson, WI) in the summer and fall of 2019 and housed in an isolated, temperature-controlled environment. Frogs were cared for by MSU Campus Animal Resources (CAR) staff for up to five days prior to utilization. This project was approved by the MSU IACUC board of Animal Use, application #03/17-039-00, and all animals were handled in accordance with institutional guidelines. We chose 21 frogs in total, allowing at least two to three frogs for each experimental dose. The frogs were immersed in various solutions of MS222 (PENTAIR AQUATIC ECO SYSTEMS Inc. Syndel, USA) ranging from 0.05% w/v (.5 g/L) to 0.30% w/v (3g/L) (i.e. 0.05%w/v, 0.08%w/v, 0.10%w/v, 0.15%w/v, 0.20%w/v, 0.25%w/v, 0.30%w/v). Experiments were performed over three separate days of testing in a temperature-controlled lab environment (26.8°C), barometric pressure (740mmHg), and relative humidity (42%). Reverse osmosis water sat in an open-top container overnight to dissipate any remaining chlorine. Water temperature reached an average of 26.1°C. Water pH was actively maintained between 7.0 and 7.4 with sodium bicarbonate and tested frequently using a calibrated water quality tester (Apera Instruments).

The frogs were submerged one at a time into MS222 immersion bath and a timer was started immediately upon submersion. Frogs were continually monitored for activity. When activity observably diminished (typically after two to three minutes), the frog was assessed for lack of pinch-withdrawal and blink reflex. If both of these endpoints were achieved, the frog was immediately removed from the solution. If not, the frog was returned to the solution and re-evaluated every 30 seconds. Once the frog was finally removed, they were immediately washed using regular tap water, dried, and weighed on a calibrated scale. Total immersion time was recorded. A second timer was started establishing subsequent removal of the frog from solution to first data collection.

Pithing

The Frog was grasped firmly and double pithed to ensure brain death. Momentary leg spasms followed by going limp was an indication that the brain and brainstem had been sufficiently destroyed. The gastrocnemius was identified and extracted via dissection and positioned on a force transducer as outlined by ADInstruments Instructor's Guide (ADI 2005). Using an external probe, the muscle specimen was directly stimulated starting at 0.05 mv, increasing every one to two seconds by 0.05 mv, reaching a final stimulation of one volt. Resulting muscle force and optimal tension force were recorded using LabChart® Software version eight, from ADInstruments. Graded muscle responses were analyzed for minimum voltage

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to elicit a response, maximal force, and optimal tension to achieve maximal force. Force was scaled for gastrocnemius muscle mass and muscle mass$^{2/3}$ (M$^{.67}$) to normalize for muscle cross-sectional area (Slobodan 2002; Clemente and Richards 2013). Any obvious changes in minimum voltage to elicit response vs. dosage were also identified. This enabled the categorization of each frog into a low dosage category vs. higher dosage category. Statistical significance was set at the P<.05.

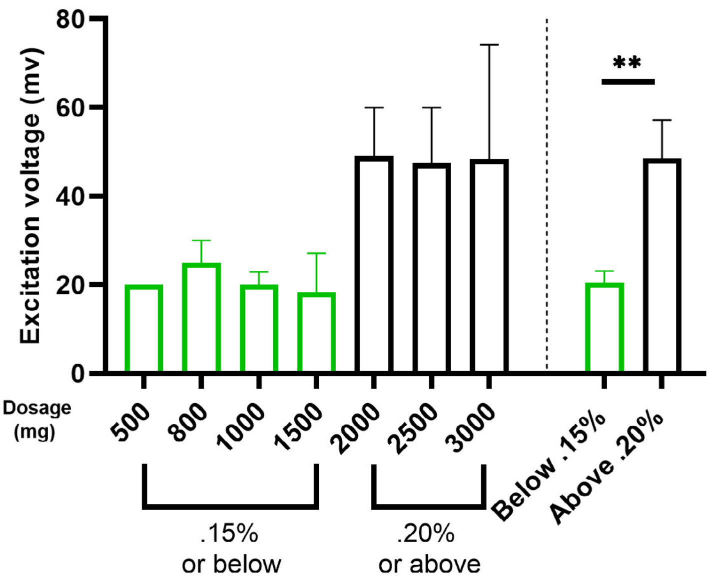
Results

Table 1 shows the project morphometrics, including mean frog weight, mean gastrocnemius weight, average immersion time in MS222, and average extraction time of the muscle specimen. Frogs were chosen at random for each dose.

Graph 1 shows that a natural separation in minimal excitation voltage was observed allowing for categorization of each frog into a low dosage group (0.15% and below) and a high dosage group (0.20% and above). After separating into their respective groups, a significant difference in minimum excitation voltage was observed (21mv $\pm$ 8 mv vs. 49mv $\pm$ 27 mv, P=0.000627) between the 0.15% and 0.20% groups respectively (Graph1).

Dosage Categories (MS-222)	.15% w/v and below	.20% w/v and above
Number of Frogs (final)	N = 11	N = 10
Average Frog Weight	19.83 ± 7.3 g	24.7 ± 7.1 g
Average Gastrocnemius Weight	373.6 ± 172.8 mg	530.2 ± 245.2 mg
Average Immersion Time***	5 min 54 ± 66 sec	3 min 42 ± 35 sec
Average Muscle Extraction Time	7 min 41± 130 sec	6 min 27 ± 43 sec

Table 1. *Morphometrics. Table 1. shows the average frog weight, gastrocnemius weight, immersion time, and extraction time between the two dose groups (low dose 0.15% w/v and high dose 0.20% w/v). ***=Significance (P< 0.0001)*



Graph 1. *Minimum excitation voltage per each dose group and between low dose and high dose groups (0.15% w/v and below vs. 0.20% w/v and above). Error bars = SEM, **=Significance (P=0.000627)*

It was evident that the frogs in the 0.20% category were on average five grams heavier (Table 1) and had a gastrocnemius muscle tissue weight on average 150 mg greater (Table 1) than those in the 0.15% group. However, they were not significantly different. Average immersion time was significantly less in the higher dosage group by over two minutes (P=0.0001) (Table 1), but extraction time was one minute less in this same group, yet did not reach statistical significance (Table 1). Frog 13 was removed from the final data analysis due to tissue compromise during the testing session.

Graph 2 shows that unpaired T-tests indicated no significant difference in absolute maximal force achieved between the low vs. high dosage groups (0.17 mN vs. 0.10 mN, P= 0.07319). However, statistically significant differences between the low and high dose groups were observed when scaled relative to muscle mass (force/muscle mass 0.58 mN vs. 0.16 mN; P=0.00032) (Graph 3) and to the mass$^{2/3}$ exponent (force/muscle mass$^{.67}$ 0.38 mN vs. 0.13 mN; P=0.000483) (Graph 4).

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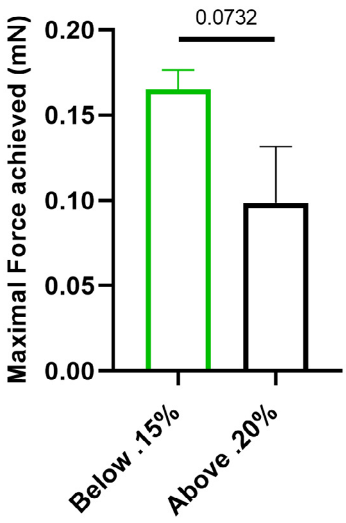
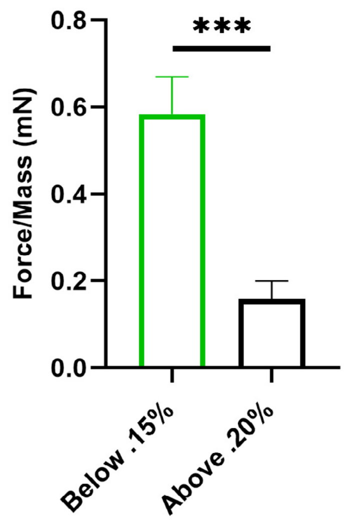
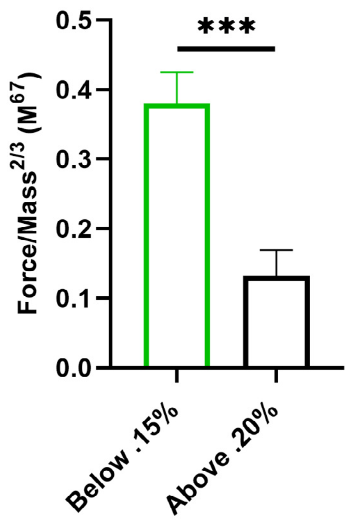


Graph 2. *Average muscle force between low dose (0.15% w/v) and high dose (0.20% w/v) groups. Not statistically significant (P=0.07219)*



Graph 3. *Force/gastrocnemius mass. Error bars = SEM,***=Significance (P<0.00032)*



Graph 4*. Force/gastrocnemius mass$^{2/3}$. Error bars = SEM,***=Significance (P<0.000483)*

Discussion

The results of these experiments show that there were identifiable differences in the excitation characteristics when directly stimulating muscle tissue after immersion in MS222 at various doses. While the difference in absolute force output was not statistically significant (Graph 2) between the low and high dosage groups, all tissue samples did respond to stimulation except one. This was different from a previous study where up to 90% of the muscle specimens tested were unable to elicit responses via direct stimulation of the muscle or via the sciatic nerve (Medler 2019). However, in that study, the frogs were immersed in 0.15% solution of MS222 for up to 30 minutes. None of the frogs in our study were immersed for more than seven minutes. This suggests that longer soaking times may essentially block greater voltage-gated Na+ channels therefore decreasing or eliminating any available tissue response.

Statistically significant differences (Graph 1) were observed in minimum excitation voltage between our low and high dosage group. Maximal force achieved did not reach statistical significance between the groups (Graph 2), but when scaled for gastrocnemius muscle mass and mass$^{2/3}$ exponent statistical significance was achieved (Graphs 3 and 4). Scaling offers a way to normalize and compare the force output of the stimulated muscle tissue (Slobodan 2002). However, a different scaling exponent would have been required if we were assessing swimming or jumping performance instead of force output (Clemente and Richards 2013). Since these frogs were of various sizes and weights, it is difficult to compare absolute force output in a larger cross-sectional muscle specimen than a much smaller muscle specimen regardless of the excitation voltage. Therefore, by scaling our data, we achieved statistical significance. This suggests to us that more viable muscle fibers were available in the low dose group vs. the high dose group.

While a Type I statistical error may have been committed with only 20 frogs used in this protocol study, there were some definite observed changes in muscle viability with an increasing dosage of MS222. These changes were most notable in the high dose group (0.20% or higher), and in a few cases, no responses recorded at 0.30% dose.

Our data support the conclusions of Medler (2019), that using dose concentrations of 0.15% or higher and immersion times of 20+ minutes may interfere with the excitation characteristics of muscle that we are attempting to elicit in our teaching labs. Based on our data, MS222 concentrations of 0.15% or less with an immersion time of five minutes or less would allow for proper muscle tissue viability while achieving AVMA guidelines towards a humane endpoint. The muscle tissue was also immediately viable. Additionally, based on our own laboratory experience, dosage levels 0.15% or below maintained tissue viability for up to two hours of testing before the tissue would no longer respond. This lower immersion time and reduction in dosage also provided a low exposure environment for our teaching team and the students handling the tissue thereafter. We have not tested this approach when stimulating the gastrocnemius indirectly via the sciatic nerve. This approach would require further study.

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Conclusion

A larger study of the dose-response relationship would provide better guidelines to instructors using MS222 in their teaching labs. The current AVMA Guidelines and recommendations may be counter to our student learning goals by reducing the viability of excitable tissue and placing students and teaching staff at a higher health risk exposure of the MS222 anesthetic.

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Literature Cited

ADInstruments©. 2005. Physiology of Skeletal Muscle. *Instructor's Guide*:3-7.

Allen JL, Hunn JB. 1986. Fate and distribution studies of some drugs used in aquaculture. *Vet Hum Toxicol* 28(1):21-24.

Attili S, Hughes SM. 2014. Anaesthetic Tricaine Acts Preferentially on Neural Voltage-Gated Sodium Channels and Fails to Block Directly Evoked Muscle Contraction. *PLOS ONE*. 9(8). Available from: doi: 10.1371/journal.pone.0103751.

American Veterinary Medical Association. AVMA Guidelines for the Euthanasia of Animals. 2013 Edition. Schaumburg, IL.: AVMA, 2013.

Beckman M. 2016. Therapeutic review: Tricaine Methaonsulfonate. *J Exot Pet Med* 25:261-263.

Bernstein PS, Digre KB, Creel DJ.1997. Retinal Toxicity Associated With Occupational Exposure to the Fish Anesthetic MS-222. *American Journal of Ophthalmology* 124(6):843–844.

Clemente CJ, Richards C. 2013. Muscle function and hydrodynamics limit power and speed in swimming frogs. *Nature Communications* 4(1):1-8.

Cross TR, Cross VE. 2004. Scalpel or mouse? *Am Biol Teacher* 66:408–411.

Franco N. 2013. Animal Experiments in Biomedical Research: A Historical Perspective. *Animals* 3(1):238–273.

Lillywhite HB, Shine R, Jacobson E, Denardo DF, Gordon MS, Navas CA, Burghardt GM. 2016. Anesthesia and Euthanasia of Amphibians and Reptiles Used in Scientific Research: Should Hypothermia and Freezing Be Prohibited? *BioScience* 67(1):53–61.

Lalonde-Robert V, Beaudry F, Vachon P. 2012. Pharmocologic parameters of MS222 and physiologic changes in frogs (Xenopus laevis) after immersion in anesthetic doses. *Journal of the American Association for Laboratory Animal Science* 51(4):464-468.

Medler S. 2019. Anesthetic MS-222 eliminates nerve and muscle activity in frogs used for physiology teaching laboratories. *Advances in Physiology Education* 43(1):69–75.

Mitchell MA. 2009. Anesthetic Considerations for Amphibians. *Journal of Exotic Pet Medicine* 18(1):40–49.

Moore WA, Noonan AC. 2010. Using live tissue laboratories to promote clinical reasoning in doctor of physical therapy students. *Advances in Physiology Education* 34(2):54–58.

Raanan AW. 2005. The evolving role of animal laboratories in physiology instruction. *Advances in Physiology Education* 29(3):144–150.

Ramlochansingh C, Branoner F, Chagnaud BP, Straka H. 2014. Efficacy of Tricaine Methanesulfonate (MS-222) as an Anesthetic Agent for Blocking Sensory-Motor Responses in Xenopus laevis Tadpoles. *PLoS ONE*. *9*(7). Available from: doi: 10.1371/journal.pone.0101606

Shore N, Khawar S, Qutab M, Ayub M. 2013. Animal Laboratory, interactive computer based learning, in enhancing basic concepts in physiology: an outlook of 481 undergraduate medical students. *J Ayub Med Coll Abbottabad* 25(1-2):57-59.

Slobodan J. 2002. Muscle Strength Testing Use of Normalisation for Body Size *Sports Med* 32(10): 615-631.

Tricaine Methanesulfonate .2015. *MSDS* No. WC005. Western Chemical Inc., Ferndale, WA.

Zubek JF. 2018. Survey of Instructors- Frog skeletal muscle anesthetic protocol. Unpublished Survey. Approved survey project by the Michigan State University, Office of Regulatory Affairs Human Research Protection Program (STUDY00001818).

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The Impact of a Bookend Think-Pair-Share Intervention on Anxiety and Student Collaboration in a Community College Human Physiology Course

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Abstract
Pre-clinical community college students represent a unique population with varied academic backgrounds and levels of preparedness. Addressing the needs of this population is important for issues of access, equity, and diversity in higher education. As part of a larger National Science Foundation (NSF) funded Community College Anatomy and Physiology Education Research (CAPER), this study aimed to investigate the impact of an active learning technique on student anxiety, student collaboration, and final course grades. We introduced a bookend think-pair-share (TPS) active learning technique into a traditional community college human physiology lecture. The study found an increased likelihood of collaboration, a slight increase in final grades, a slight decrease in social anxiety, and a significant decrease in anxiety regarding five of eight specific teaching practices following the bookend TPS intervention. https://doi.org/10.21692/haps.2019.030

Key words: anxiety, think-pair-share, peer instruction, active learning, community college

Introduction
Community college students aiming for careers in the health sciences arrive with varied academic backgrounds and wide-ranging levels of preparedness. These students often struggle with success in Human Physiology courses, a common prerequisite for many allied health programs. Community colleges, which are generally two-year open-enrollment public institutions, have a distinctive mission compared to many four-year universities, including serving those students with less access to traditional higher education. But, with broader access often comes a diverse student population: community college students are more likely to be first-generation status (36% v. 25% at 4-year), lower socioeconomic status, and have less experience with prior academic achievement than most students at 4-year institutions (Fong et al. 2017). These students are also very likely to be employed part-time or full-time and to be of nontraditional age (Juszkiewicz 2015). Therefore, when assessing issues of access, equity, and diversity in higher education, it is crucial to consider the unique factors impacting community college student success.

Students in college biology courses also often struggle with understanding and verbalizing the causal reasoning for physiological phenomena (Michael 1998). Both the language of physiology and difficulty interpreting physiological graphs, equations, and flowcharts can make the material in Human Physiology classes challenging to master (Michael 2007). Although lecturing is a traditional delivery method for a Human Physiology course, collaborative active learning approaches such as Peer Instruction (i.e. think-pair-share or TPS) have been shown to improve student performance in science and health-care related classes (Sumangala and DiCarlo 2018; Freeman et al. 2014; Prahl 2017).

Poor performance in science courses correlates with increased student anxiety and a low sense of academic self-efficacy and often has implications beyond the courses in question (Bandura 1977). Students with higher levels of anxiety perceive tests as threatening and tend to think they have less control over outcomes. High levels of academic anxiety correlate with a decreased likelihood of success on assessments and a negative experience with the educational process. Negative experiences are important considerations for the community college student, because negative experiences encourage disengagement from formal academic learning in a population with fewer academic successes to fall back on (Cassady 2004).

Research has shown that one effective strategy to decrease student anxiety and improve academic self-efficacy is to provide mastery experiences that have the same or similar tasks as a future summative assessment task (Bandura 1977). Low-stakes formative assessment opportunities, in which students can discuss and correct their knowledge can provide opportunities for mastery, decrease anxiety, and result in

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better performance in summative assessments. Fostering a collaborative, rather than competitive, classroom culture, with peer interaction, may also help reduce the negative impacts of student anxiety.

Mazur (1997) describes a structured series of steps called Peer Instruction (i.e. think-pair-share or TPS) designed to emphasize student interaction during lectures and focus students' attention on the underlying concepts. The method begins with a short conceptual multiple-choice question called a "ConcepTest" that focuses on a single topic. The type and phrasing of the question matters, though; open-ended ConcepTest questions that require verbalization of processes to arrive at a conclusion foster student interaction and discussion more effectively than questions that require a simple recall of information (Allen and Tanner 2005). After presenting the ConcepTest question, the instructor allows students time to answer the question alone, then provides time to consult with peers and answer the question again, and finally presents the correct answer and provides an opportunity for discussion with the class (Mazur 1997).

The TPS technique can easily be modified to include personal response systems (PRS) to ensure that every student is participating in the activity and to allow the instructor to give immediate feedback based on responses received. Another modification to the TPS technique is to use the ConcepTest question to "bookend" a traditional lecture by posing the question, allowing for students to answer individually, then lecturing over the concept (but not the specific question), before posing the same question again, this time allowing time for TPS and class discussion. This modification encourages students to focus attention on the concept initially with the presentation of the question, allows them time to process and critically evaluate their initial response, and prepares them for the discussion that they will have when they engage in the collaboration step (Smith et al. 2005). Integrating TPS opportunities within a traditional lecture format provides students the opportunity to verbalize their thoughts about physiological concepts using appropriate terminology, to correct misconceptions in a low-stakes environment, and promotes communication and comparison of ideas among classmates, and can encourage a collaborative, rather than competitive, classroom culture, especially if the instructor helps to foster inquiry and reinforces the process as well as correct responses. Paired or small group discussion can also decrease the anxiety often associated with students speaking out in class, providing a less daunting opportunity to verbalize ideas with one or a few peers first (Tanner 2013).

Mazur (1997) states that TPS, "forces the students to think through the arguments being developed and provides them (as well as the teacher) with a way to assess their understanding of the concept". TPS has also been shown to improve performance on quizzes (Sumangala and DiCarlo 2018). In addition, if, as reported, students find the causal reasoning associated with Human Physiology difficult, then modeling and providing opportunities to practice this kind of reasoning during class (using carefully worded ConcepTest questions) with real-time instructor feedback could lead to higher summative assessment scores and decreased stress (Michael 2007).

Although TPS has been implemented and evaluated in multiple studies, we did not find evidence in the literature that the bookend TPS technique had been tested in the community college population.

As part of a larger study on pedagogical practices in anatomy and physiology courses at the community college level, this research introduced a bookend TPS technique administered with electronic personal response systems into a traditional lecture-based human physiology course and attempted to answer three questions:

1. Does a bookend TPS activity administered during formative assessment improve final grades?
2. Does the use of a TPS activity decrease student anxiety?
3. Does a TPS activity increase the likelihood of student collaboration?

Methods

Student Population

This research was implemented in two 30-student Human Physiology (BIOL2420) lecture sections taught at Salt Lake Community College (SLCC) by the same instructor. Each class met twice per week for 80 minutes. Students enrolled in Human Physiology at SLCC are primarily second-year students majoring in pre-health science or an undeclared major. The majority of these students intend to apply to nursing programs or other allied health programs such as radiology, occupational therapy assistant, and physical therapy assistant. SLCC students are required to complete Introductory Biology and Elementary Chemistry with a C or better as a prerequisite for Human Physiology, and most students have also completed Human Anatomy, although it is not a prerequisite for the course. Students must also enroll in Human Physiology laboratory (BIOL2425), as a corequisite. Human Physiology is often the last course a student will take before applying to an allied health program or transferring to a four-year college to complete a bachelor's degree. At SLCC, 42% of our student population self-report as first generation, whereas 42% report as not first generation and 14% do not report their status. Moreover, 75% of the student population works more

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than 30 hours per week (Figure 1). Thus increasing in-class comprehension in this population with less formal academic experience and considerable time constraints is crucial to student success.

Bookend Think-Pair-Share

The Institutional Review Board (IRB) of Salt Lake Community College found this research project to be exempt form IRB review (IRB# 00009566, FWA00021259). Informed consent was obtained from all participants. TPS questions were administered during two 80-minute lecture sections per week during Spring semester 2019. During most lecture periods, a conceptual multiple-choice question was presented twice (with a short lecture between the questions). Using Top Hat, an electronic PRS, students answered the question alone, then listened to the material, then collaborated and answered again, comparing answers to other student answers, with the instructor providing anonymous histograms of student responses and real-time feedback. Mazur (1997) describes the seven steps that constitute the traditional Peer Instruction method as follows.

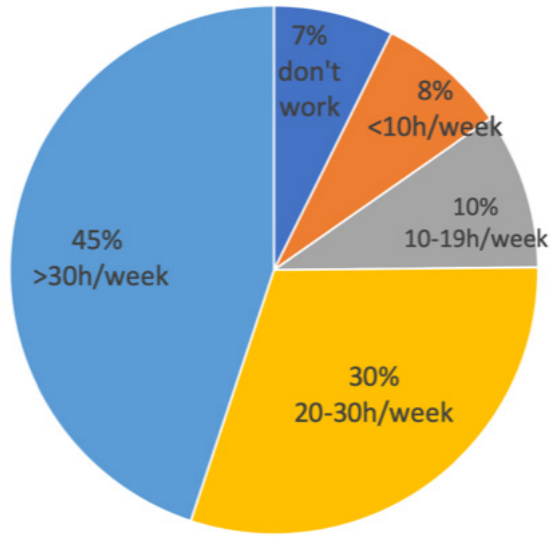

Figure 1. *Working students at SLCC*

1. Students are presented a conceptual multiple-choice question (ConcepTest question). Questions followed published guidelines for designing effective multiple-choice questions, with a correct answer and viable distractors that elicit common misconceptions about the concept (Haladyna et al. 2002). An example ConcepTest question is provided in Figure 2.

All of these factors impact stroke volume. Which of these do you predict will DECREASE stroke volume?

A increased venous return to the atria

B increased strength of ventricular contraction

C increased pressure in the arteries near the heart

D increased blood volume in the ventricles

Figure 2. *Sample ConcepTest question.*

2. Students were then given one minute to think before answering the question.

3. Students respond using PRS. Student responses and correct answers were not shared with the class at this point. As a modification to Mazur's original Peer Instruction method, at this point a short lecture was presented about the physiological concept assessed in the ConcepTest question. The lecture did not cover the specific question, or the answer the ConcepTest question, but guided students through understanding the concept and modeled logic that could be used in answering the question and the vocabulary used to explain the concept.

4. The same question was presented again after the short lecture. During the collaboration portion students were asked to pair with another student and discuss what each initially answered. Students attempted to convince their partner if their answers differ and to verbalize their arguments whether they agreed or disagreed. Students were instructed to use physiological terminology presented in the lectures when appropriate and to be prepared to discuss their answers with the class. This TPS portion was allotted three to five minutes.

5. Students were given one minute to answer the same question again.

6. The correct answer and an anonymized student response histogram were shared with the class. Students are awarded credit for participation (not for accuracy) for answering the question alone and in pairs. This was an important component of TPS that encourages collaboration and correcting misconceptions.

7. Instructor asked students to share their logic about correct answers and distractors and guided a class discussion about the reasoning used to arrive at the correct answer.

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Because research indicates that providing mastery experiences with the same or similar questions used on summative assessments can reduce student anxiety, similar questions to those used during think-pair-share were used on summative assessments as multiple choice, essay, or short answer questions (Bandura 1977).

Grade Analysis
In order to assure both students and the college IRB that assignment of final course grades was not influenced by participation in the study, grade analysis was performed only after final student grades were reported to the college. Final grades after the intervention were compared to final grades in a previous semester of the same course from the same instructor, which was used as a control. The previous course used for comparison was randomly selected, had approximately the same enrollment (30-35 students), also met for 80-minutes twice per week, used PRS (but not TPS), used the same lecture text, had similar lecture exams, and had the same laboratory activities.

Anxiety and Collaboration
Students were asked to complete a self-report measure rating their agreement with statements related to anxiety on a Likert scale at the beginning and the end of the semester. To test whether social anxiety changed with the treatment, we performed a dependent t-test on student reports of social anxiety using a modified Mini-SPIN general and social anxiety inventory before (N=67) and after the treatment (N=51) (Connor et al. 2001, Pintrich and DeGroot 1990). Test anxiety was measured using items from the Revised Test Anxiety Scale (RTA) (McIlroy et al. 2000).

Student anxiety regarding specific in-class teaching practices was measured using items from an existing sub-scale of a validated instrument designed to measure anxiety levels toward research, modified to measure anxiety levels toward biology instruction (England et al. 2017). We tested for differences in anxiety pre- and post-treatment about eight in-class teaching practices: listening to a PowerPoint lecture, volunteering answers posed by the instructor, answering cold-call questions, individual low-stakes (<5% of grade) quizzing, group low-stakes quizzing, TPS, PRS quizzing in pairs, and PRS quizzing alone. Significant differences in task-related anxiety were identified using MANOVA using SPSS statistical software (Field 2013).

Student responses to the question "Do you have any comments or suggestions about the use of Think-Pair-Share, especially in challenging courses?" were subjected to thematic analysis. The comments were examined for common themes, and trigger words for each theme were identified. Two researchers, other than the course instructor, independently calculated the number of times each theme appeared in the comments. The independent researchers compared their results and came to a consensus.

At the end of the semester, students were also asked whether the intervention impacted the likelihood that they would form a study group or collaborate with other students. Open-ended comments from students regarding the intervention were collected and will be presented in the results section.

Results

Grades
Students performed better on each bookend TPS question after a short lecture and collaborating with their peers. Although students were given credit for participation regardless of the accuracy of answers, we calculated the percent correct on each bookend ConcepTest question, before and after collaboration. On average, students scored 62% correct on ConcepTest questions before collaboration and 86% correct after (Figure 3).

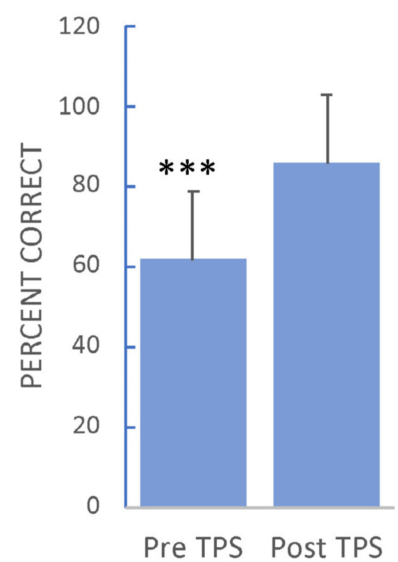

Figure 3. *Percent correct responses to ConcepTest questions, pre- and post-TPS collaboration (mean +/- SD; ***, P<0.001).*

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We assessed whether this modified TPS technique administered during formative assessments improved final course grades. In order to test this, we ran an independent t-test comparing the final grades of a randomly-selected previous spring semester (in which the technique wasn't used) to the final grades of this semester. We found a modest, but not significant, difference, in which students using the bookend TPS instruction technique performed slightly better (mean = 83.0827 *SD* = 13.38369) compared to those students from a previous semester who did not use the technique (mean= 78.5590, *SD* =14.45638), $t(111)$ - 1.72, p = .089.

Anxiety

While Mini-SPIN measures of social anxiety were lower in the post test (N= 51 M = 2.97 SD = 1.20) compared to pretest (N=67 mean=3.24 *SD* = 1.06), this difference did not reach significance, $t(48) = 1.628$, p=.11.

A MANOVA of anxiety reports regarding eight specific in-class activities showed a significant difference in anxiety levels from pre to post, $F(3,46) = 8.434$, $p < .001$ (Figure 5). Follow-up univariate analysis reveals that there was no significant anxiety difference in three of the activities: listening to a lecture, volunteering answers posed by the instructor, and cold-calling from the instructor. However, both PRS activities (alone and with a partner) showed that mean anxiety about the activity decreased significantly in the post test compared to pretest (for conditions alone and with another student).

Mean anxiety regarding low-stakes quizzing (alone and with a group) also decreased significantly in the post test compared to pretest, for conditions with a group and alone, respectively. Mean anxiety about the specific intervention, TPS, decreased significantly in the post-test compared to the pretest.

	Beginning of term (n=67)	**End of term (n=51)**	*p*
	Mean Anxiety +/- SD	Mean Anxiety +/- SD	
Total social anxiety	3.24 ± 1.06	2.97 ± 1.20	0.11
Task-specific anxiety			
Group low-stakes quiz	2.24 ± 1.27	1.8 ± 0.978	< 0.05
Individual low-stakes quiz	2.36 ± 1.12	1.73 ± 0.850	< 0.001
TPS	2.1± 1.12	1.67 ± 0.971	< 0.01
PRS pairs	2.42 ± 1.17	1.92 ±1.077	< 0.01
PRS individual	2.3 ± 1.20	1.57 ± .677	< 0.001

Table 1. *Mean perceived anxiety, pre- and post-intervention, (0 = no anxiety, 5= extreme anxiety)*

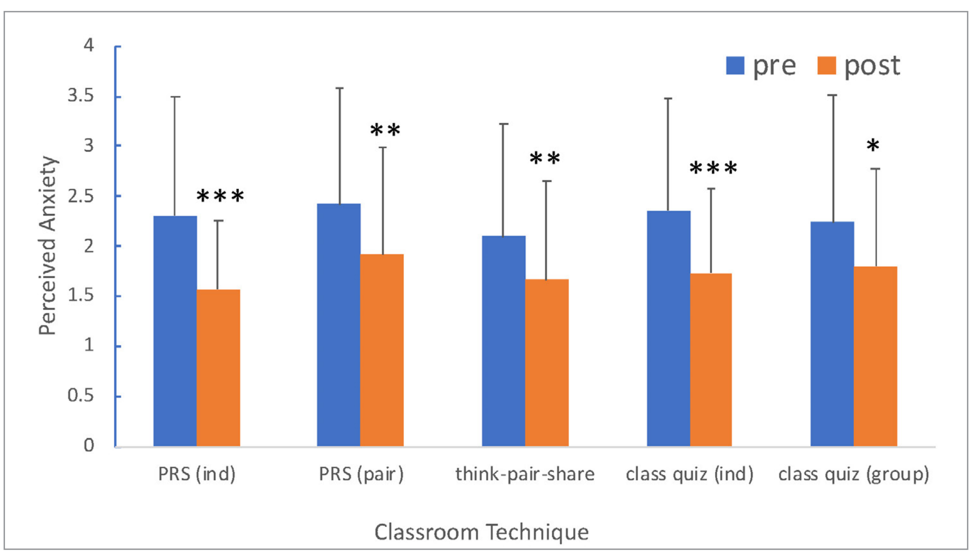

Figure 4. *Perceived task-related anxiety pre- and post-intervention (mean +/- SD; *, <0.05; **, P<0.01; ***, P<0.001, MANOVA). Students reported task-related perceived anxiety on a scale of 1 (low anxiety) to 5 (extreme anxiety).*

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Thematic analysis of open-ended comments

Thirty-four students provided response to the open-ended question "Do you have any comments or suggestions about the use of Think-Pair-Share, especially in challenging courses?" As shown in Table 2, six overlapping themes were identified. Thirty-two of the thirty-four comments conveyed a positive perception of the think-pair-share technique, and (15) indicated that they found the group aspect especially helpful. Four students commented that the discomfort or anxiety associated with group work helped their learning; an equal number indicated that the anxiety impaired their ability to learn. Students also indicated that the technique helped them prepare for exams (4) and/or fostered deep learning and critical thinking (6).

Theme	Explanation	Trigger Words	Sample Comment	n (out of 34)
Positive Perception	Student experiences the implementation of Think-Pair-Share in a positive way	• Helpful • Useful • Enjoy • Beneficial • Effective • Great • Liked • Loved	"I think that think-pair-share should be used in every class. it was very useful to have to think it through in your own words and to get a second explanation from another student."	32
Enabling Discomfort/ Anxiety	The discomfort/ anxiety the student experiences when participating in Think-Pair-Share activities enables the student's learning or contributes to growth	• Comfort zone • Step out • Talk • Peers • Get out • Nervous • But • Helped	"I was really nervous about it at the beginning of the semester but I found it very helpful and was glad we used it"	4
Impairing Discomfort/ Anxiety	The discomfort/ anxiety the student experiences as a result of the implementation of Think-Pair-Share impairs the student's ability to learn	• Anxiety • Anxious • Insecure • Intimidating • Time factors • Loud	"Some of them were a little tricky and I have bad anxiety when time is a factor on things."	4
Test Preparation	Student found Think-Pair-Share useful for test preparation	• Exams • Test • Questions • Material • Study • Prepare • Expect	"I think that the think-pair-share activity made me think about the material before I learned the material. this alone really helped my study. I tried to use these types of methods in later times that I studied."	4
Group Learning	Student found the group aspect of Think-Pair-Share useful	• Group • Peers • Partner • Collaborate • Discuss(ion)	"Being able to collaborate and talk about the questions with people in the class I wouldn't have otherwise talked to was extremely helpful."	15
Deep Learning	Student prioritizes deep understanding of class concepts	• Critical thinking • Engage(ing/ed) • Understand • Concepts • Material • Reasoning	"I think more teachers should use think-pair-share. it helps with critical thinking, gets the class involved and engaged, and I felt like it helped me understand the material better."	6

Table 2. *Student responses to the question "Do you have any comments or suggestions about the use of Think-Pair-Share, especially in challenging courses?"*

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Student collaboration

We polled students (N=67) at the end of the term to see if they were more or less likely to collaborate or study with peers following a semester of TPS intervention. Thirty-five percent reported that they were more likely, 42% reported that the likelihood was about the same, and 1% reported that they were less likely. Some positive and negative comments regarding student collaboration are presented below. Both the survey and the student comments seem to indicate that most students are more likely to collaborate with their peers following the intervention.

Positive comments	**Negative comments**
Being able to collaborate and talk about the questions with people in the class i wouldn't have otherwise talked to was extremely helpful. Whether I was getting help from them or teaching them, I was always learning.	Yes it forces you to work with others, but it doesnt facilitate a way to make the group work any less intimidating.
It was very useful to have to think it through in your own words and to get a second explanation from another student. it made understanding difficult concepts easier because students would explain it in "layman's" terms.	For the share portion, I think it would be good to encourage collaboration with different students each time. It's helpful to mix it up and be exposed to different ways of thinking and approaches. I normally don't like working out the answer with other people but it actually helped a lot to hear them explain and help me to learn it more.
It allowed me to learn from my peers or teach them things that I felt I knew well. It also broke the ice for the people around me forcing us to interact. this made it easier to colab with the people that I did the tps with.	It help a little but can also be hard when you don't really know anyone or the answer to the questions being asked you can feel more insecure about things you don't know.
I really enjoyed answering the question alone first, learning material and then coming back to it and collaborating with classmates	
I liked the think pair share because I learned to think about the question on my own, learn the material from the professor, then go over the question again with my peers and having it explained to me differently and having the opportunity to explain it to them to make sure I really understand the material.	

Table 3. *Selected student comments regarding collaboration.*

Discussion

Although active learning techniques, student collaboration, and student anxiety have been studied extensively, a gap remains in the literature regarding the impact of specific active learning techniques on the community college student experience. The unique challenges of this student population - academic unpreparedness for college-level work, time constraints due to financial stresses, and disproportionately first-generation college student status - necessitate that college instructors reflect carefully about both presentation and assessment. As part of a larger National Science Foundation (NSF)-funded grant encouraging community college instructors to incorporate evidence-based instructional practices in their courses, this study specifically assessed the impact of one practice on the community college student, with specific concerns of these students in mind.

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Course Grades
Students performed better on the conceptual questions after a short lecture and discussion with their peers. Our findings are consistent with earlier demonstrations of the value of social learning, including the value of discussion with peers. Smith et al. (2009) found that peer discussion increases understanding on conceptual questions, even when none of the students in the group initially knows the answer.

There was no statistical difference in final course grades when compared to a previous semester. Further study and a larger sample size may reveal whether the intervention may have an impact on course grades. Regardless, course grades were not negatively impacted, and other factors were significantly positively impacted by the intervention.

Task-specific Anxiety and Social Anxiety
The statistically significant decreases in task-specific anxiety related to PRS quizzing, in-class quizzing and TPS activities were also encouraging, and might indicate that students were more comfortable with both critical thinking - because the ConcepTest questions required application and verbalization of knowledge - and collaboration - because engaging in the TPS activities was a low-stakes interaction with class members. Some reports indicate that close to half of first-generation college students drop out within their first year, and, although most students in this study were second-year students, increasing critical thinking and collaboration in this population could have lasting positive impacts on their academic prospects in any stage of their studies (Xu and Jaggars 2011).

Although it was encouraging that self-reported social anxiety decreased in the post-intervention survey when compared to the pre-intervention survey, this difference also did not reach significance. A larger sample size might allow us to determine whether the recorded lower social anxiety could be attributed to the intervention.

Student collaboration
One encouraging and unanticipated side effect of the bookend TPS intervention was that many students reported that they were more likely to collaborate and study with peers after the intervention. The instructor's role in facilitating a TPS activity is to be clear that students need not get the answer correct or agree in order to benefit, and also to emphasize that practicing the problem-solving aspect of physiology is an essential part of learning about physiology (Tanner 2013). The TPS technique reinforces collaboration by awarding credit for participation in the discussion instead of credit for correct answers, which seemed to be an important consideration for anxious students. By charging students to compare ideas and identify points of agreement and disagreement and then encouraging open discussion, students seemed to get into the practice of verbalizing their ideas. In a challenging course that requires interpreting data and graphs and verbalizing causal reasoning, collaboration with other students should prove beneficial, especially for the less academically experienced student.

Conclusion

Community college students represent a unique population that is often less academically prepared, more pressed for time due to financial obligations and work schedules, and more easily discouraged from academics than the traditional college student population (Fong et al. 2017, Juszkiewicz 2015). Community colleges serve these students by providing broader access to higher education than most 4-year institutions, and consequently community colleges tend to have a more diverse student body. Retaining these students in the STEM disciplines must be a priority, and active learning techniques have been identified as one means of fostering inclusivity and potentially reducing the achievement gap faced by underrepresented groups in STEM (Snyder et al. 2016).

This study investigated a single active learning technique within a single course. Since our study found a decrease in task-specific anxiety about several in-class teaching practices after the intervention, and students also reported greater likelihood of collaboration, this type of intervention may be beneficial for increasing student success and retention in the diverse community college population. Student comments indicated that most students had a positive perception of the intervention, and found the group learning aspect of TPS helpful, an important consideration for the community college student, because negative experiences encourage disengagement from academics, especially in community college students (Cassady 2004). Small group discussion with peers can provide a less intimidating venue to verbalize ideas, practice critical thinking, and collaborate. These results highlight the need for additional research regarding active learning techniques within the community college population.

One notable limitation of this study was the small sample size: only 67 students in two classes over the course of a single semester precludes generalizing the conclusions to larger groups. More power through a larger sample might allow us to detect whether differences in course grades and social anxiety would reach statistical significance. Further study using a control group within the same class or the same semester would allow more confidence that the intervention is responsible for the differences observed. Considering that this study was performed with second-year community college students who already had some experience and success with college-level science courses, future work exploring the technique with first-year community college students, a group that studies indicate is very likely to discontinue their studies when faced with barriers, would be interesting (Xu and Jaggars 2011).

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It would also be interesting to determine whether the patterns indicated by this small study would be reflected with multiple instructors in a larger sample within community college students and/or would vary with university students within the first two years of their STEM studies.

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Literature Cited

Allen D and Tanner K. 2005. Infusing active learning into the large-enrollment biology class: seven strategies, from the simple to complex. *Cell Biol Educ* 4: 262–268. doi: https://doi.org/10.1187/cbe.05-08-0113

Bandura A. 1977. Self-efficacy: toward a unifying theory of behavioral change. *Psychol Rev* 84: 191. doi: https://doi.org/10.1037/0033-295X.84.2.191

Cassady JC. 2004. The influence of cognitive test anxiety across the learning-testing cycle. *Learn Instruct* 14:569-592. doi: https://doi.org/10.1016/j.learninstruc.2004.09.002

Connor KM, Kobak KA, Churchill LE, Katzelnick D and Davidson JR. 2001. Mini-SPIN: A brief screening assessment for generalized social anxiety disorder. *Depress Anxiety* 14:137–140. doi: **https://doi.org/10.1002/da.1055**

England BJ, Brigati JR, Schussler EE. 2017. Student anxiety in introductory biology classrooms: perceptions about active learning and persistence in the major. *PLOS ONE* 12(8):e0182506. Available from: https://journals.plos.org/plosone/article?id=10.1371/journal.pone.0182506. doi: https://doi:10.1371/journal.pone.0182506.

Field A 2013. Discovering Statistics Using IBM SPSS Statistics. Los Angeles, CA: Sage Publications.

Fong CJ, Davis CW, Kim Y, Kim YW, Marriott L, and Kim S. 2017. Psychosocial factors and community college student success: a meta-analytic investigation. *Rev Educ Res* 87: 388-424. https://doi.org/10.3102/0034654316653479

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, and Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. *PNAS* 111 (23) 8410-8415. doi: https://doi.org/10.1073/pnas.1319030111

Haladyna TM, Downing SM, and Rodriguez MC. 2002. A review of multiple-choice item-writing guidelines for classroom assessment. *Appl Measure Educ* 15:309–344. doi: https://doi.org/10.1207/S15324818AME1503_5

Juszkiewicz J. 2015. Trends in community college enrollment and completion data, 2015. American Association of Community Colleges, 1-7.

Mazur E. 1997. Peer Instruction, A User's Manual. Upper Saddle River, NJ: Prentice Hall.

McIlroy D, Bunting BM and Adamson G. 2000. An evaluation of the factor structure and predictive utility of a test anxiety scale with reference to students' past performance and personality indices. *Br J Educ Psychol* 70:17–32. doi: https://doi.org/10.1348/000709900157949

Michael JA.1998. Students' misconceptions about perceived physiological responses. *Adv Physiol Educ* 19: 90–98. https://doi.org/10.1152/advances.1998.274.6.S90

Michael JA. 2007. What makes physiology hard for students to learn? Results of a faculty survey. *Adv Physiol Educ* 31: 34-40. doi: https://doi.org/10.1152/advan.00057.2006

Pintrich PR and DeGroot EV.1990. Motivational and self-regulated learning component of classroom academic performance. *J Educ Psychol* 82:33–40.

Prahl K. 2017. Best practices for the think-pair-share active-learning technique. *The Am Biol Teach* 79(1): 3–8. doi: 10.1525/abt.2017.79.1.3

Smith KA, Sheppard SD, Johnson DW, and Johnson RT. 2005. Pedagogies of engagement: classroom-based practices. *J Engr Educ* 94(1):87-101January 2005. 1–16. doi: https://doi.org/10.1002/j.2168-9830.2005.tb00831.x

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Smith MK, Wood WB, Adams WK, Weiman C, Knight JK, Guild N, and Su TT. 2009. Why peer discussion improves student performance on in-class concept questions. *Science* 323: 122-124. doi: 10.1126/science.1165919

Snyder JJ, Sloane JD, Dunk RDP, Wiles JR. 2016. Peer-Led Team Learning Helps Minority Students Succeed. *PLOS Biol* 14:e1002398. doi: https://doi.org/10.1371/journal.pbio.1002398

Sumangala P and DiCarlo S. 2018. Peer instruction improves performance on quizzes., *Adv Physiol Educ* 24: 51-56. doi: https://doi.org/10.1152/advances.2000.24.1.51

Tanner KD, 2013. Structure matters: twenty-one teaching strategies to promote student engagement and cultivate classroom equity. *CBE Life Sci* 12:3. doi: https://doi.org/10.1187/cbe.13-06-011

Xu D and Jaggars SS. 2011. The effectiveness of distance education across Virginia's community colleges: evidence from introductory college-levels math and English courses. *Educ Eval Policy Anal* 33:360-377. doi: https://doi.org/10.3102/0162373711413814

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Unraveling the Epididymis: A Review of Its Structure and Function

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Abstract
The epididymis is an oft-overlooked structure of the male reproductive system which plays an important role in sperm maturation, motility, storage and protection. The purpose of this review is two-fold: first, to provide an update from the current literature on what is known about the epididymis with regards to structure, histology, and function, and second, to separate those characteristics of the human epididymis that are unique from other non-human models. This review will also attempt to demonstrate that the epididymis is an excellent model to expand on general concepts learned throughout the Human Anatomy and Physiology classroom experience. https://doi.org/10.21692/haps.2020.007

Key words: Epididymis, sperm maturation, sperm storage

Introduction

When reproduction is discussed in the Human Anatomy and Physiology classroom, focus is generally placed on the gonads and the process of gametogenesis. In the male, gametogenesis occurs in the testis, while in the female, oogenesis occurs in the ovary. The end-product of oogenesis results in a fertilization-competent gamete. Spermatogenesis, on the other hand, yields a less-than-competent gamete that must undergo further maturation beyond the testicular tissue to become fertilization-competent. To provide students a more complete picture of the process of spermatozoan maturation, it is important to also emphasize the epididymis, the excurrent duct that lies between the testis and the ductus deferens. It is the structure of the male reproductive system responsible for transforming immotile fertilization-incompetent spermatozoa arriving from the testis into the rigorously motile, oocyte-recognizing, fertilization-competent gamete needed for syngamy.

The epididymis is not unique to humans or even mammals. It has been identified in many different vertebrates including rays, sharks, salamanders, lizards, and birds, as well as mammals (Jones 1999) as part of the male excurrent duct system, which includes the epididymis, ductus deferens, and urethra (Robaire and Hinton 2015). Species that possess epididymides commonly practice internal fertilization, thus the epididymis is considered to be a hallmark reproductive organ for internally fertilizing, vertebrate species (Sullivan et al. 2019).

Different organisms have adopted a variety of reproductive strategies to improve their reproductive success in light of sexual competition within their particular species. Mammals, in particular, exhibit a great deal of variability in male reproductive anatomy. One structure that exhibits a wide range of variability across mammalian species is the epididymis. Most studies of the epididymis have been performed using rodent and large domesticated animal models, but a variety of other mammals, including human, have also served as the subject of epididymal studies. Human epididymal gross anatomy and histology can be reasonably described from tissues obtained from necropsy (Turner 2008; Sullivan et al. 2019). Regnier De Graaf first described the dissection of the human epididymis in 1668 as originating "as six or seven branches at the top of the testicle… that run together into one duct… which gradually enlarges… [to form] the vas deferens" (Turner 2008).

Functionally, it is fairly well established, that regardless of species the epididymis plays an important role in sperm maturation, transport, storage, and protection (Robaire and Hinton 2015). While significant headway has been made over the last twenty years to identify how these functions are regulated and carried out at the molecular level, there is still much to be discovered. Most of what we do understand about epididymal function comes from non-human studies, especially research using bovine and rodent model systems. Human epididymal biochemical research is limited because access to healthy tissue is extremely limited (Sullivan and Mieusset 2016). Because structure and function are related, and because epididymal structure variability is reflective of reproductive strategy, we must be cautious in extrapolating biochemical functions across species when there are significant variations in structure. Concerning the regulatory mechanisms and molecular signaling pathways that have been discovered, we are limiting this review to gross anatomy, histology and general function for the purposes of teaching Human Anatomy and Physiology. The molecular regulatory pathways are beyond the scope of this review. This

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review intends to shed light on both gross and histological structure as well as general function of the epididymis across all species. In addition, this review intends to examine the unique difference between humans and non-human models to present a clearer picture of the structure and function of the human epididymis for use in the Human Anatomy and Physiology classroom.

It should be noted that there have been times when non-human structural observations have been extrapolated to human structure, which has led to errors in the teaching texts. When considering the structure and function of the epididymis, in light of the variability across species, it is important to carefully consider the source model for what is taught about humans in the Human Anatomy and Physiology classroom.

Anatomy of the Human Epididymis

The epididymis is a structure so named because it lies next to the testis (Robaire and Hinton 2015). Each testis has its own epididymis that are collectively are referred to as the epididymides. Each epididymis is medially attached to its testis, both overlaid by the tunica vaginalis. In rodents, an epididymal fat pad can be found partly covering the epididymis, while in humans this fat pad has been reported as present (Turner 2008), but has also been found to be absent (Sullivan et al. 2019). The epididymis originates at the efferent ducts at the postero-superior pole of the testis, then circumnavigates along the postero-medial edge to reach the inferior pole of the testis. From here, the epididymis makes a hairpin turn, travels in a superior direction on the posterior side of the testis, and transitions into the vas deferens (Figure 1). As an organ, the epididymis in a typical human is about 10-12 cm in length (Turner 2008). Within the capsule of the organ is a highly convoluted tubule that is three to six meters in length (Robaire and Hinton 2015) that originates in the caput region and terminates at the vas deferens. The tubule typically originates from the initial segment with a small-diameter lumen and a surrounding thin layer of smooth muscle. As the tubule progresses through the caput towards the vas deferens, the lumen of tubule increases in diameter, the epithelium becomes thinner, and the thickness of the smooth muscle increases (Elfgen et al. 2018; Sullivan et al. 2019).

Organization of the epididymis can be confusing given the different ways the anatomy is described. Classical anatomical nomenclature may divide the epididymis into two regions, the globus major which refers to the proximal epididymis and the globus minor which refers to the distal epididymis (Turner 2008). The more common nomenclature, which reflects the structure of the epididymis in most animal models, separates the epididymis into four regions (proximal to distal): the initial segment (which is often placed within the caput as a region), the caput (head), the corpus (body), and the cauda (tail) (Robaire and Hinton 2015). Further divisions have also

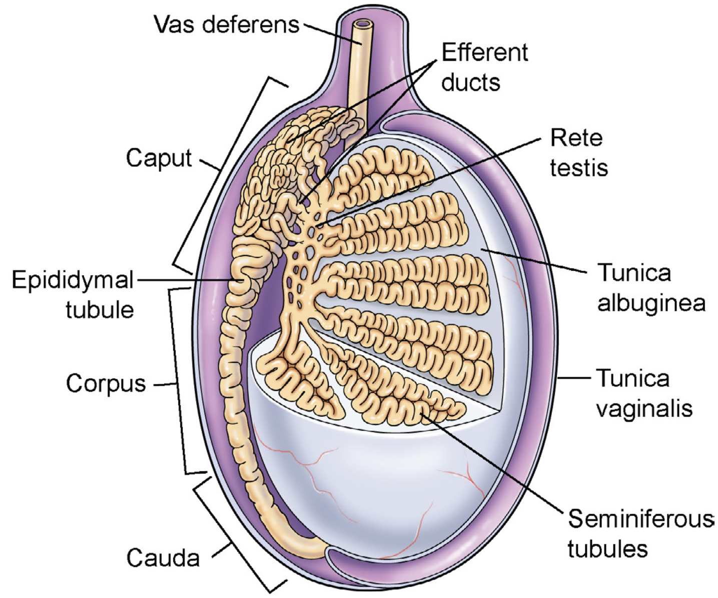

Figure 1. *Human epididymis and testis. Illustration representing the organization of the seminiferous tubules, rete testis, efferent ducts, epididymis, and vas deferens. Note that the epididymis is divided into three regions, the caput, corpus, and cauda. The efferent ducts connect the rete testis to the epididymal duct. Several efferent ducts leave the rete testis, enter the caput, and occupy a significant portion of the caput before converging on the single epididymal duct in the caput.*

been delineated (*e.g.* the proximal vs. the distal caput), to help better define functional roles for the various regions but which are not particularly useful given that these delineations lack uniformity across specimens and studies. More recently, the epididymis has been shown to be segmented into intraregional compartments defined by connective tissue septa that may serve to partition the epididymis into discrete functional lobules (Turner et al. 2003; Jelinsky et al. 2007; Domeniconi et al. 2016). For the purposes of teaching Human Anatomy and Physiology, the human epididymis is best described as possessing three regions; the caput, corpus, and cauda (Figure 1), which aligns well with general function (discussed later).

One area in which there are significant differences between human and the non-human models is in the anatomy of the caput. Humans are unique in that they lack an initial segment (Turner 2008; Sullivan et al. 2019). The cells and duct structure of the initial segment have been described as being histologically distinct from the rete testis, the efferent ducts, and the epididymal ducts of the caput (Sullivan and Mieusset 2016). Histological examination of the human caput fails to demonstrate the tell-tale cuboidal epithelium that is characteristic of the initial segment in other species and of the rete testis in all species (Saitoh et al. 1990; Turner 2008).

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Instead, the majority of the caput in humans is occupied by the efferent ducts identifiable by a ciliated columnar epithelium that appear abruptly at the junction with the extra-testicular rete testis (Saitoh et al. 1990; Yeung et al. 1991; Sullivan et al. 2019). In addition, the efferent ducts are significantly smaller in diameter than the epididymal ducts and are irregularly shaped (Turner 2008; Sullivan et al. 2019). Several models of mammalian species typically exhibit short and straight efferent ducts arising from the rete testis that connect to the initial segment of the epididymis. Human efferent ducts, however, pass into the caput coiling tortuously into lobules (Yeung et al. 1991). Some of these ducts branch, then anastomose to join the epididymal duct proper while others do not connect to the epididymis tubule at all (Saitoh et al. 1990; Yeung et al. 1991).

During development, as the epididymal tubule begins to coil, connective tissue septa form to separate the epididymis into distinct regions (Johnston et al. 2005; Jelinsky et al. 2007; Domeniconi et al. 2016). The mouse epididymis, for example, is divided by septa into ten unique segments (Johnston et al. 2005), whereas rats develop 19 segments (Jelinsky et al. 2007). The septa that define these segments appear well-organized and are conserved among specimens (Sullivan et al. 2019). Segments and septa have also been observed in at least five other mammalian species (Domeniconi et al. 2016). Multiple studies suggest that these septa form boundaries that create compartments for unique gene expression and protein production (Johnston et al. 2005; Jelinsky et al. 2007; Guyonnet et al. 2009; Zhang et al. 2011), create boundaries that limit signaling between segments (Turner et al. 2007), and even create an immunological barrier between them (Stammler et al. 2015).

Again, the human epididymis stands out as unique among the mammals in terms of structure. The human epididymis has historically been described as having from five to ten septa (Domeniconi et al. 2016). However, more recent studies have demonstrated that the human septa are incomplete, lack the organization that allows for unique segments to be defined, and vary in location between specimens. The only exception is the septum that separates the caput between the efferent ducts and the epididymal duct, which clearly demarks the boundary between these two tubular structures (Sullivan et al. 2019).

The smooth muscle layer surrounding the epididymal epithelium changes in organization along the length of the tubule. For example in the caput, the smooth muscle cells are thin and concentrically arranged around the tubule (Elfgen et al. 2018). The smooth muscle layers become thicker as the tubule progresses towards the vas deferens, gaining not only greater numbers of smooth muscle cells but also differently arranged bundles. In the corpus, longitudinal and oblique bundles of large smooth muscle cells are observed external to the concentric layer. As the corpus transitions to the cauda, more large smooth muscle cells are added to form a complete layer with a mostly longitudinal orientation (Elfgen et al. 2018). Where the thin smooth muscle cells have been observed (in the caput and corpus, but not in the cauda), spontaneous contractions have also been observed (Elfgen et al. 2018). The amount and arrangement of smooth muscle found in a given region can serve as an identification tool to distinguish one region from the next.

Cells of the Epididymis

The epithelium of the epididymal duct is described as pseudostratified and consists of a variety of cell types connected together by tight junctions (Belleannée et al. 2012; Breton et al. 2019; Sullivan et al. 2019). Seven cell types are typically described as making up the lumen of the duct: apical cells, basal cells, clear cells, dendritic cells, halo cells, narrow cells, and principal cells. Of these, the apical cells and narrow cells have been detected in the initial segment of rodents and have not been found in humans (Robaire and Hinton 2015; Sullivan et al. 2019). The remaining five cell types, which are found in humans, appear to be responsible for human epididymal function (Figure 2).

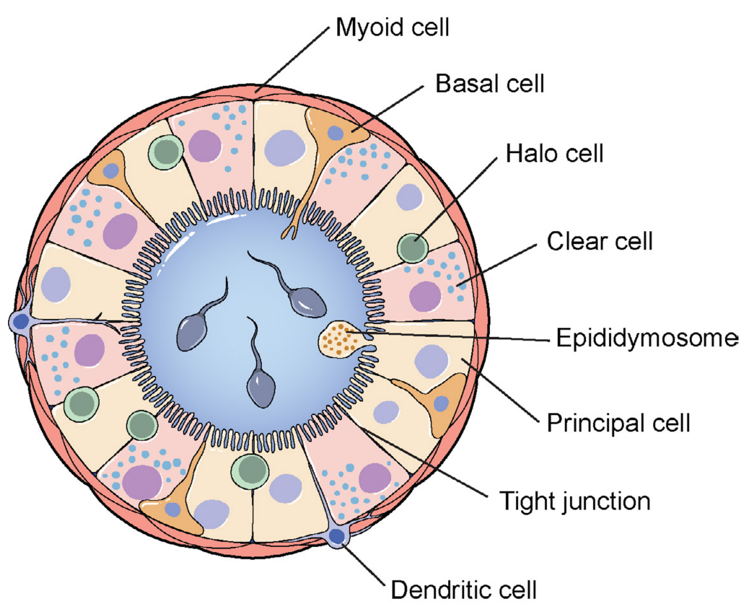

Figure 2. *Cross section of the human epididymal epithelium. Illustration representing the organization of the epididymal tubule and the locations of the five major cell types that makeup the pseudostratified epithelium in humans. Tight junctions are found at the apical ends of the cells creating a blood-epididymis barrier. A principal cell is shown secreting an epididymosome through which materials are transferred to maturing spermatozoa transiting through the lumen of the tubule.*

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Principal cells are the most common type of epididymal cell making up 65-80% of the total cell population. They are located throughout the epididymis (Belleannée et al. 2012; Robaire and Hinton 2015). Depending on their location, they exhibit structural differences that may imply functional differences within the region in which they are found. In the caput, for example, principal cells are tall, columnar cells with a basally-located, ovoid nucleus. In the cauda, the principal cells exhibit a more cuboidal shape and exhibit other morphological differences in their appearance and organization (Belleannée et al. 2012; Robaire and Hinton 2015; Breton et al. 2019; Sullivan et al. 2019).

The primary function of the principal cell is to synthesize and release proteins into the luminal fluid either by a merocrine or an apocrine mechanism. Through this latter secretory method, principal cells produce epididymosomes that play an important role in transferring proteins to the spermatozoa that are traveling through the epididymis. A variety of epididymosomal proteins have been shown to contribute to spermatozoa motility, fertilization capacity, protection against reactive oxygen species, and identification of defective spermatozoa (Björkgren and Sipilä 2019). In addition, principal cells are responsible for transporting substances (*e.g.* water, ions, bicarbonate, ATP) to and from the luminal fluid that are important for epididymal function (Belleannée et al. 2012; Breton et al. 2019; Sullivan et al. 2019).

The larger clear cells are found in all three regions of the epididymis, with a greater number present in the cauda than in the caput (Shum et al. 2009). They appear to have two primary functions, acidification and endocytosis. Clear cells express vacuolar proton pumps which help to contribute to the acidic environment of the epididymis (Breton et al. 1996). These pumps are associated with sub-apical vacuoles until luminal stimuli direct the cells to move the pumps to the apical surface where they can promote the acidification of the luminal fluid (Belleannée et al. 2012). A low pH, especially in the cauda, creates an environment that promotes the spermatozoa into a quiescent state (Sullivan et al. 2019). In addition, clear cells have numerous coated pits and lysosomes indicating an endocytotic role. For example, clear cells have been shown to endocytose cytoplasmic droplets released from spermatozoa and even exhibit region-specific uptake of different proteins (Belleannée et al. 2012; Robaire and Hinton 2015).

Basal cells are pyramid-shaped cells found throughout all three regions of the epididymis that are attached to the basement membrane of the epididymal duct. Basal cells possess slender projections that are directed between the surrounding cells toward the lumen (Belleannée et al. 2012; Robaire and Hinton 2015; Breton et al. 2019). While these projections are typically found below the level of the tight junctions at the apical pole of the epithelium, the basal cell may actively penetrate beyond the tight junction to "sample" luminal fluid composition (Shum et al. 2008). Basal cells also exhibit coated vesicles on their basal surface (facing the basement membrane) and on their surfaces facing the principal cells. While it is not yet clear what role the basal cells play in the epididymis, it has been proposed that they may sample the tubular fluid through their attenuations as well as receive signals through the blood to influence the activity of the principal cells (Belleannée et al. 2012; Arrighi 2014; Robaire and Hinton 2015). Other functions that have been proposed for basal cells include protection against reactive oxygen species (O'Flaherty 2019) and regulating principal cells through prostaglandin secretion (Leung et al. 2004).s It has even been proposed that basal cells may act as stem cells for principal and clear cells in the epididymis (Mandon et al. 2015; Pinel et al. 2019).

The last two types of cells function as the immune cells of the epididymis: the halo cell and the dendritic cell. Halo cells are found along the entire length of the epididymis near the base of the epithelium, but exhibit a greater abundance in the proximal regions. The halo cell is small and possesses a narrow rim of cytoplasm surrounding a large nucleus (Robaire and Hinton 2015). Immunolabeling has demonstrated that halo cells are a mixed population of T_H lymphocytes, T_C lymphocytes, and monocytes (Flickinger et al. 1997; Serre and Robaire 1999).

Dendritic cells are located along the basement membrane of the epididymal lumen and have been identified as antigen-presenting cells responsible for regulating the immune response. Dendritic cells exhibit different characteristics depending on where they are located. For example, dendritic cells in the caput extend short projections towards the lumen similar to the basal cell, while in the cauda dendritic cells lack projections and lay along the base of the lumen (Da Silva et al. 2011; Breton et al. 2019). Distinct cell markers also suggest that there are mixed dendritic cell subpopulations along the length of the epididymis, and that there are more dendritic cells localized to the caput than the cauda (Voisin et al. 2018; Breton et al. 2019). It has also been proposed that dendritic cells may clear defective spermatozoa and epithelium from the epididymal lumen (Da Silva and Smith 2015). Ultimately, the primary function of antigen-presenting dendritic cells, regardless of where they reside, is to direct innate and adaptive immune responses. It is likely that dendritic cells are responsible for the same in the epididymis. Together the halo cells and dendritic cells serve as the first line of defense against infection and help to maintain the environment of the epididymis.

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The Blood-Epididymis Barrier

It is well established that the testis possesses a dynamic blood-testis barrier that separates the developing germ cells from the blood and interstitial fluid. The epididymis extends this barrier by keeping the blood separate from the spermatozoa and epididymal fluid (Robaire and Hinton 2015). The blood-epididymis barrier primarily consists of apically-located tight junctions with contributions from adherens and gap junctions found between principal cells (and clear cells when present) (Robaire and Hinton 2015). These junctions form a continuous anatomic barrier between the luminal fluid and the surrounding interstitium and intercellular spaces.

The epididymis clearly establishes two specific physiological environments as the result of this anatomic barrier: the combined extraluminal blood plasma and interstitial fluid compartment and the intraluminal fluid compartment. This serves a broader purpose of allowing the epididymis to maintain a specialized microenvironment for the maturing spermatozoa within its lumen (Robaire and Hinton 2015). If ions and macromolecules must pass through the principal cells rather than circumnavigating between them, the epididymis may regulate which materials may be passed between the two compartments. In doing so, the epididymis also establishes a physiological barrier that allows it to create unique fluid compositions along its length to meet the specific needs of the spermatozoa as they pass through the epididymis (Robaire and Hinton 2015).

The third component of the blood-epididymis barrier is the immunological barrier. In an anatomical sense the barrier prevents antibodies and immunocytes from penetrating into the lumen of the tubule. Similarly, it sequesters spermatozoa antigens within the lumen to ensure that spermatozoa can develop without interference from immunological attack. It is yet to be determined what role the immune cells (halo and dendritic cells) have in the blood-epididymis barrier, but given the evidence that infection may be contained within epididymal regions (at least in rodents), the immune cells may serve as first line of defense against infection akin to an epididymal-associated lymphatic tissue.

Function of the epididymis

Four functions have been assigned to the epididymis: transport of spermatozoa, spermatozoan maturation, spermatozoan storage, and spermatozoan protection (Robaire and Hinton 2015). In order to accomplish these functions, the epididymal epithelium creates and regulates unique luminal compartments that allow each of these tasks to be completed within the different segments. In organisms with distinct septa, it is easy to imagine the epididymis as an assembly line of maturation with distinct structural units responsible for specific steps, ultimately delivering the mature spermatozoa to the caudal end for storage and protection until the time of ejaculation (Domeniconi et al. 2016). While humans lack complete septa (Sullivan et al. 2019), gene expression exhibits a pattern of compartmentalization akin to what have been observed in other species (Sullivan and Mieusset 2016). Thus, it is important to cautiously extrapolate observations from other model systems to what occurs in humans.

In humans, a cohort of spermatozoa released from the seminiferous epithelium of the testis passes through the rete testis and enters the epididymis via the efferent ducts. The primary force driving these spermatozoa into the epididymis is the flow of testicular fluid with some assistance from the actions of the ciliated cells of the efferent duct epithelium (Robaire and Hinton 2015; Sullivan et al. 2019). Interestingly, the total transit time along the length of the epididymis is roughly the same across all species, averaging about ten days for all species regardless of differences in length of the epididymis (Robaire and Hinton 2015). It appears that the transit time through the caput and corpus is more or less constant regardless of species. Transit time variation between species occurs primarily in the cauda which serves as the site of spermatozoa storage (Robaire and Hinton 2015).

While there are several methods to measure transit time through the epididymis, the most common way is to radiolabel germ cell DNA during spermatogenesis and follow the progression of the spermatozoa as they pass through the epididymis (Robaire and Hinton 2015). Studies have shown that the average time for a cohort of spermatozoa to be completely transported through the epididymis is always slower than the leading vanguard of spermatozoa regardless of the species examined (Robaire and Hinton 2015; Sullivan et al. 2019). That the complete cohort does not arrive all at the same time at the distal end of the epididymis suggests that there is a mixing of different spermatozoa cohorts as they transit through the caput and corpus. In humans, the leading vanguard of spermatozoa arrive in the distal regions of the epididymis approximately two days after entering into the epididymis, which is significantly earlier than most other species (Robaire and Hinton 2015). Still, the average transit time through the entire epididymis for human spermatozoa is approximately 12 days, similar to the ten day universal average for all species examined (Robaire and Hinton 2015). It should be noted that different studies have demonstrated a wide variation in transport rates in humans (Sullivan et al. 2019). More robust studies to accurately describe human spermatozoa transport rates through the epididymis still need to be performed.

The cauda serves as the stored spermatozoa reservoir for ejaculation, so luminal flow is impaired by fluid reabsorption and spermatozoa concentration at the distal end of the epididymis. This, plus the normal resistance that any fluid encounters passing through a tube, leads to an ever-growing hydrostatic pressure gradient that the flowing epididymal

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fluid and maturing spermatozoa must overcome (Robaire and Hinton 2015). Epididymal cells which possess microvilli but lack cilia cannot propel spermatozoa (Sullivan et al. 2019). Thus, spermatozoa propulsion from caput to cauda is primarily dependent on epididymal smooth muscle contraction. Most studies on epididymal smooth muscle contraction have been performed in non-human models, so whether these studies reflect human smooth muscle activity remains to be determined. Contraction in the proximal region of the epididymis has been characterized as spontaneous and rhythmic. Distally, contractions become less frequent but their strength increases. In the cauda, contractions are sporadic with some regions exhibiting no spontaneous contractions at all (Mewe et al. 2006; Elfgen et al. 2018). These rhythmic contractions can move in both directions and may serve to mix spermatozoa cohorts as they travel through the epididymis. In addition to rhythmic contractions, peristaltic contractions have also been observed which propel spermatozoa towards the cauda (Elfgen et al. 2018).

Neural, endocrine, and luminal factors affect smooth muscle contraction. The epididymis is innervated by sympathetic adrenergic fibers throughout, with concentrations of adrenergic receptors increasing from caput to cauda (Elfgen et al. 2018). Sympathetic stimulation of the cauda has also been implicated in spermatozoa emission (Ricker 1998; Mewe et al. 2007). Several endocrine and luminal factors can also change the rate of smooth muscle contraction. For example, testosterone relaxes smooth muscle, leading to a slower spermatozoa transport rate, while estrogen increases the rate of contraction and thus a faster transport rate (Robaire and Hinton 2015; Elfgen et al. 2018). Other factors that have been implicated in epididymis smooth muscle contraction include oxytocin/vasopressin, prostaglandins, serotonin, eNOS, and angiotensin II (Elfgen et al. 2018). In addition, luminal fluid and spermatozoa can modify the rate of smooth muscle contraction (Mewe et al. 2006), demonstrating that the regulation of smooth muscle contraction is complex and in need of further investigation.

It has been well established that the spermatozoa become functionally mature as they pass through the epididymis regardless of species (Robaire and Hinton 2015; Sullivan and Mieusset 2016). The process of spermatozoan maturation includes acquiring the ability of forward motility outside of the epididymis as well as the ability to ascend the female reproductive tract. Additionally, spermatozoa acquire the ability to undergo the acrosome reaction as well as the ability to recognize and bind the oolema to ultimately achieve syngamy with the oocyte. This concept of spermatozoan maturation is based on *in vitro* fertilization assays and artificial inseminations performed with spermatozoa collected from various regions of the epididymis (Robaire and Hinton 2015). While spermatozoa collected from similar regions (*e.g.* the distal caput) in different species exhibit different degrees of fertilization-competence, the data has demonstrated that spermatozoa must traverse a minimal length of epididymis to reach fertilization competency, regardless of species (Robaire and Hinton 2015; Sullivan and Mieusset 2016). The most common locale across species from which the first functional spermatozoa can be isolated is the mid-corpus (Sullivan and Mieusset 2016).

Several studies in animal models have begun to identify what modifications are occurring to the spermatozoon as it passes from caput to corpus. These modifications involve changing the sperm's lipid composition, surface charge, binding properties, and microdomain restructuring; as well as, modifying glycoproteins and other surface markers (Robaire and Hinton 2015; Sullivan and Mieusset 2016). Dynamic restructuring including nuclear chromatin condensation, acrosomal reshaping, organelle modification, and cytoplasmic removal also occurs (Robaire and Hinton 2015; Sullivan and Mieusset 2016). Epididymosomes secreted by the principal cells play a major role in adding the factors that lead to maturation including proteins, lipids, and small non-coding RNAs (Björkgren and Sipilä 2019). The current hypothesis is that different populations of principal cells along the length of the epididymis secrete specialized epididymosomes with unique factors that lead to the sequential maturation process observed along the length of the epididymis (Sullivan 2015; Björkgren and Sipilä 2019).

Spermatozoa captured from the testis exhibit little to no motile activity, whereas ejaculated sperm exhibit vigorous, progressive motility indicating that the epididymis is the structure where spermatozoa gain their ability to swim. Just as each epididymal region result in different modifications to the maturing spermatozoa, the spermatozoa transiting along the length of the epididymis also gain distinct swimming abilities (Yeung et al. 1993). For example, spermatozoa captured from the caput exhibit the ability to swim in a circular pattern. However, spermatozoa captured from the cauda exhibit the vigorous forward motility observed in ejaculated sperm (Robaire and Hinton 2015).

The cauda serves as the sperm reservoir. Mature sperm arrive in the cauda, where water and other components are removed and factors that maintain sperm in a quiescent state and protect them against oxidative damage are added to the luminal milieu (Robaire and Hinton 2015; Sullivan et al. 2019). Early animal studies suggest that sperm may be stored in the cauda for periods longer than a month and still maintain their functionality (Robaire and Hinton 2015). In polygamous species, the sperm reservoir contains enough sperm for 10-12 ejaculates. In contrast, humans are more or less monogamous animals, so the human cauda contains only enough sperm for two to three ejaculates (Sullivan et al. 2019). When compared to other species including non-human primates, the human cauda is poorly developed (Sullivan et al. 2019).

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Finally, the epididymis plays an important role in protecting sperm. While the blood-epididymis barrier and the epididymal immune cells play a significant role in immunological protection, it should also be noted that the epididymis must protect sperm from reactive oxygen species (ROS) to which they are highly susceptible given the elevated content of polyunsaturated fats in sperm plasmalemma (Vernet et al. 2004). While some ROS are necessary to produce the types of modification necessary to create functional sperm, too much ROS can be damaging (Vernet et al. 2004; O'Flaherty 2019). In epididymides with well-defined septa, each region has developed its own unique strategy to protect again ROS (Robaire and Hinton 2015). Because the septa create separate compartments along the length of the epididymis for the purpose of specialized metabolic activity, those compartments will produce different ROS that must be appropriately eliminated. Similarly, as spermatozoa transit along the length of the epididymis, their changing nature elicits unique strategies to protect them from oxidative damage. While different strategies to protect against ROS along the length of the epididymis have been employed by multiple mammalian species with complete septa (Vernet et al. 2004; Robaire and Hinton 2015; O'Flaherty 2019), it remains to be determined whether the lack of complete septa in the human epididymis has resulted in a distinct specialized strategy for ROS protection.

Conclusion

In the Human Anatomy and Physiology classroom, the epididymis is an oft-overlooked structure, often relegated to the role of either extra-testicular structure or proximal structure in the male reproductive duct pathway. This review attempts to describe the epididymis in more detail. It is more than just a structure for sperm storage, but a necessary structure needed to complete the process of sperm maturation. While the human epididymis is less understood than other animals, the functional and structural components of the epididymis in general will allow a clearer understanding of male reproductive strategy.

In gross anatomical terms, the human epididymis has clearly defined structure. Most texts adopt the commonly used three regional divisions of caput, corpus, and cauda, which is probably the best approach. However, what defines the boundaries between these regions is often ignored. Encouraging students to seek out differences between the regions (beyond diameter) will help them better understand how anatomists explore structure. For example, the amount and type of smooth muscle present is one way to distinguish between the regions. Use of a dissection microscope might allow students to examine septa and define their own boundaries and hypothesize where the regions are delineated. Use of a light box will also allow students to compare tissue density to help them identify unique regions. For example, the region of the caput containing the efferent ducts appears dark due to tissue compactness, while the cauda appears dark due to the thickness of the smooth muscle layers (Sullivan et al. 2019). Students can recognize these simple differences and understand organization better.

Histologically, the human epididymis has some unique properties that are useful in the classroom. Regional variation is easily observed. This includes cell populations, luminal structures, and luminal diameter. Examining the thickness of the smooth muscle layers as the epididymis progresses toward the vas deferens will help students connect structure to function. Students can be challenged to think about why the tube widens along its length or why cell populations change. A cross-section of epididymis demonstrating incomplete septa can serve to challenge students to think about how compartmentalization works and the effect incomplete septa might have on maintaining compartmentalization.

Beyond just the basic structural and functional attributes of the organ, the epididymis is also an excellent model system to explore anatomical and physiological themes. For example, the epididymis can be used as a model to explore unique cell populations and their roles in an epithelium. Like the nephron or capillary, the epididymal tubule can serve as a model to study fluid dynamics in a tubule. When discussing apocrine secretion, the epididymosome can be used as an example. Moreover, like the thyroid, testis and central nervous system, the epididymis' specialized barrier can be used to demonstrate that this protective strategy to confer immunoprivilege is wide-spread. Structurally the blood-epididymis barrier can be used as a model to explore different types of cell junctions. Finally, it is an interesting structure for comparative anatomy given the uniqueness of the structure in humans and other mammals. In this context, it could even be useful for understanding reproductive development, and more broadly, reproductive strategies in the context of evolution and sexual competition.

Students are required to learn so much out of context: cell structure, tissue organization, and cell junctions; yet, rarely are they shown the relevance of this material as a course progresses. Organs like the epididymis allow students to apply that knowledge and see the significance of the concepts taught in that introductory material. As instructors, we can point towards organs like the epididymis (and any other relevant structures) early in the Human Anatomy and Physiology sequence to allow students to see the value of the concept. Similarly, we can also point back to a concept (e.g. apocrine secretion) when discussing the epididymis to demonstrate the connectivity of the material. In so doing, students will gain a deeper appreciation and understanding for the structures as well as the physiological themes. It also helps to reduce the cognitive load for the student when they first learn concepts and then build on them as they study system after system.

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For such a small structure, the epididymis is amazingly complex and surprisingly important to reproductive success. In this review, we have explored some of the complexities of this forgotten structure and demonstrated its usefulness.

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Literature Cited

Arrighi S. 2014. Are the basal cells of the mammalian epididymis still an enigma? *Reprod Fertil Dev*. 26(8):1061–1071. doi:10.1071/RD13301.

Belleannée C, Thimon V, Sullivan R. 2012. Region-specific gene expression in the epididymis. *Cell Tissue Res*. 349(3):717–731. doi:10.1007/s00441-012-1381-0.

Björkgren I, Sipilä P. 2019. The impact of epididymal proteins on sperm function. *Reproduction*. 158(5):R155–R167. doi:10.1530/REP-18-0589.

Breton S, Nair AV, Battistone MA. 2019. Epithelial dynamics in the epididymis: role in the maturation, protection, and storage of spermatozoa. *Andrology*. 7(5):631–643. doi:10.1111/andr.12632.

Breton S, Smith PJ, Lui B, Brown D. 1996. Acidification of the male reproductive tract by a proton pumping (H+)-ATPase. *Nat Med*. 2(4):470–472. doi:10.1038/nm0496-470.

Da Silva N, Cortez-Retamozo V, Reinecker H-C, Wildgruber M, Hill E, Brown D, Swirski FK, Pittet MJ, Breton S. 2011. A dense network of dendritic cells populates the murine epididymis. *Reproduction*. 141(5):653–663. doi:10.1530/REP-10-0493.

Da Silva N, Smith TB. 2015. Exploring the role of mononuclear phagocytes in the epididymis. *Asian J Androl*. 17(4):591–596. doi:10.4103/1008-682X.153540.

Domeniconi RF, Souza ACF, Xu B, Washington AM, Hinton BT. 2016. Is the Epididymis a Series of Organs Placed Side By Side? *Biol Reprod*. 95(1):10. doi:10.1095/biolreprod.116.138768.

Elfgen V, Mietens A, Mewe M, Hau T, Middendorff R. 2018. Contractility of the epididymal duct: function, regulation and potential drug effects. *Reproduction*. 156(4):R125–R141. doi:10.1530/REP-17-0754.

Flickinger CJ, Bush LA, Howards SS, Herr JC. 1997. Distribution of leukocytes in the epithelium and interstitium of four regions of the Lewis rat epididymis. *Anat Rec*. 248(3):380–390. doi:10.1002/(SICI)1097-0185(199707)248:3<380::AID-AR11>3.0.CO;2-L.

Guyonnet B, Marot G, Dacheux J-L, Mercat M-J, Schwob S, Jaffrézic F, Gatti J-L. 2009. The adult boar testicular and epididymal transcriptomes. *BMC Genomics*. 10:369. doi:10.1186/1471-2164-10-369.

Jelinsky SA, Turner TT, Bang HJ, Finger JN, Solarz MK, Wilson E, Brown EL, Kopf GS, Johnston DS. 2007. The rat epididymal transcriptome: comparison of segmental gene expression in the rat and mouse epididymides. *Biol Reprod*. 76(4):561–570. doi:10.1095/biolreprod.106.057323.

Johnston DS, Jelinsky SA, Bang HJ, DiCandeloro P, Wilson E, Kopf GS, Turner TT. 2005. The mouse epididymal transcriptome: transcriptional profiling of segmental gene expression in the epididymis. *Biol Reprod*. 73(3):404–413. doi:10.1095/biolreprod.105.039719.

Jones RC. 1999. To store or mature spermatozoa? The primary role of the epididymis. *Int J Andro*l. 22(2):57–67. doi:10.1046/j.1365-2605.1999.00151.x.

Leung GPH, Cheung KH, Leung CT, Tsang MW, Wong PYD. 2004. Regulation of epididymal principal cell functions by basal cells: role of transient receptor potential (Trp) proteins and cyclooxygenase-1 (COX-1). *Molecular and Cellular Endocrinology*. 216(1):5–13. doi:10.1016/j.mce.2003.10.077.

Mandon M, Hermo L, Cyr DG. 2015. Isolated Rat Epididymal Basal Cells Share Common Properties with Adult Stem Cells. *Biol Reprod*. 93(5):115. doi:10.1095/biolreprod.115.133967.

Mewe M, Bauer CK, Schwarz JR, Middendorff R. 2006. Mechanisms regulating spontaneous contractions in the bovine epididymal duct. *Biol Reprod*. 75(4):651–659. doi:10.1095/biolreprod.106.054577.

Mewe M, Wulfsen I, Middendorff R, Bauer CK. 2007. Differential modulation of bovine epididymal activity by oxytocin and noradrenaline. *Reproduction*. 134(3):493–501. doi:10.1530/REP-07-0220.

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O'Flaherty C. 2019. Orchestrating the antioxidant defenses in the epididymis. *Andrology*. 7(5):662–668. doi:10.1111/andr.12630.

Pinel L, Mandon M, Cyr DG. 2019. Tissue regeneration and the epididymal stem cell. *Andrology*. 7(5):618–630. doi:10.1111/andr.12635.

Ricker DD. 1998. The autonomic innervation of the epididymis: its effects on epididymal function and fertility. J Androl. 19(1):1–4.

Robaire B, Hinton BT. 2015. Knobil and Neill's Physiology of Reproduction. 4th ed. Plant TM, Zeleznik AJ, editors. Elsevier. [accessed 2020 Feb 13]. https://linkinghub.elsevier.com/retrieve/pii/C20111072880.

Saitoh K, Terada T, Hatakeyama S. 1990. A morphological study of the efferent ducts of the human epididymis. *Int J Androl*. 13(5):369–376. doi:10.1111/j.1365-2605.1990.tb01045.x.

Serre V, Robaire B. 1999. Distribution of immune cells in the epididymis of the aging Brown Norway rat is segment-specific and related to the luminal content. *Biol Reprod*. 61(3):705–714. doi:10.1095/biolreprod61.3.705.

Shum WWC, Da Silva N, Brown D, Breton S. 2009. Regulation of luminal acidification in the male reproductive tract via cell-cell crosstalk. *J Exp Biol*. 212(Pt 11):1753–1761. doi:10.1242/jeb.027284.

Shum WWC, Da Silva N, McKee M, Smith PJS, Brown D, Breton S. 2008. Transepithelial projections from basal cells are luminal sensors in pseudostratified epithelia. *Cell*. 135(6):1108–1117. doi:10.1016/j.cell.2008.10.020.

Stammler A, Hau T, Bhushan S, Meinhardt A, Jonigk D, Lippmann T, Pilatz A, Schneider-Hüther I, Middendorff R. 2015. Epididymitis: ascending infection restricted by segmental boundaries. *Hum Reprod*. 30(7):1557–1565. doi:10.1093/humrep/dev112.

Sullivan R. 2015. Epididymosomes: a heterogeneous population of microvesicles with multiple functions in sperm maturation and storage. *Asian J Androl.* 17(5):726–729. doi:10.4103/1008-682X.155255.

Sullivan R, Légaré C, Lamontagne-Proulx J, Breton S, Soulet D. 2019. Revisiting structure/functions of the human epididymis. *Andrology*. 7(5):748–757. doi:10.1111/andr.12633.

Sullivan R, Mieusset R. 2016. The human epididymis: its function in sperm maturation. *Hum Reprod Update*. 22(5):574–587. doi:10.1093/humupd/dmw015.

Turner TT. 2008. De Graaf's thread: the human epididymis. *J Androl.* 29(3):237–250. doi:10.2164/jandrol.107.004119.

Turner TT, Bomgardner D, Jacobs JP, Nguyen Q a. T. 2003. Association of segmentation of the epididymal interstitium with segmented tubule function in rats and mice. *Reproduction*. 125(6):871–878. doi:10.1530/rep.0.1250871.

Turner TT, Johnston DS, Jelinsky SA, Tomsig JL, Finger JN. 2007. Segment boundaries of the adult rat epididymis limit interstitial signaling by potential paracrine factors and segments lose differential gene expression after efferent duct ligation. *Asian J Androl.* 9(4):565–573. doi:10.1111/j.1745-7262.2007.00302.x.

Vernet P, Aitken RJ, Drevet JR. 2004. Antioxidant strategies in the epididymis. Mol Cell Endocrinol. 216(1–2):31–39. doi:10.1016/j.mce.2003.10.069.

Voisin A, Whitfield M, Damon-Soubeyrand C, Goubely C, Henry-Berger J, Saez F, Kocer A, Drevet JR, Guiton R. 2018. Comprehensive overview of murine epididymal mononuclear phagocytes and lymphocytes: Unexpected populations arise. *J Reprod Immunol.* 126:11–17. doi:10.1016/j.jri.2018.01.003.

Yeung CH, Cooper TG, Bergmann M, Schulze H. 1991. Organization of tubules in the human caput epididymidis and the ultrastructure of their epithelia. *Am J Anat*. 191(3):261–279. doi:10.1002/aja.1001910306.

Yeung CH, Cooper TG, Oberpenning F, Schulze H, Nieschlag E. 1993. Changes in movement characteristics of human spermatozoa along the length of the epididymis. *Biol Reprod*. 49(2):274–280. doi:10.1095/biolreprod49.2.274.

Zhang YL, Zhang JS, Zhou YC, Zhao Y, Ni MJ. 2011. Identification of microRNAs and application of RNA interference for gene targeting in vivo in the rat epididymis. *J Androl.* 32(6):587–591. doi:10.2164/jandrol.111.013060.

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A Human Hip Dissection Technique Based on a Landmark Nineteenth-Century Experiment

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Abstract
Hip disarticulation is among the most difficult joint dissections performed in human anatomy laboratories. A literature review was conducted to identify factors contributing to hip stabilization with the objective of minimizing dislocation force. Experiments conducted by nineteenth-century brothers Wilhelm and Eduard Weber first demonstrated the role of atmospheric pressure in resisting femoral head distraction. Modern experimental research has shown the force (F) required to overcome the hip fluid seal is given by $F=(\pi D^2/4)*(P_a-P_i)$, where D is femoral head diameter (m), P_a is atmospheric pressure (N/m^2), and P_i is synovial fluid pressure (N/m^2). Equilibration of pressures $(P_a-P_i=0)$ thus minimizes required dislocation force. Standard hip dissections were performed with the additional step—inspired by Weber and Weber—of drilling a hole in the acetabulum. After drilling, most hips dislocated easily without recourse to leverage. We conclude the drill-hole technique reduces dislocation force while allowing students to directly observe factors contributing to human hip stability. https://doi.org/10.21692/haps.2019.031

Key Words: hip dislocation, hip fluid seal, pressure differential, acetabular labrum, zona orbicularis

Introduction

Cadaver dissection is a cornerstone of human anatomy education. Dissection of joints is particularly valuable, as it permits direct observation of relationships between structure and function of intact joints as well as their separate components. Disarticulation of the hip is among the most difficult joint dissections routinely performed in human gross anatomy laboratories. Even with capsular ligaments removed, the force required to disarticulate the femoral head can be as high as 120–150 N (Nepple et al. 2014; Weber and Weber 1836; 1837). It is therefore not uncommon for student dissectors to accidentally fracture the femur or acetabulum of geriatric donors or to disrupt soft tissue structures, particularly the acetabular labrum. These outcomes are suboptimal from both practical and educational perspectives. New approaches to hip dissection that improve anatomical specimen quality, minimize donor trauma, and reduce student frustration are therefore desirable.

The distinguished German physicist Wilhelm Eduard Weber and his equally renowned brother, anatomist and physiologist Eduard Friedrich Weber (Figure 1), first described a role for atmospheric pressure in stabilizing the hip against distractive forces, as well as a simple method to neutralize this stabilizing effect (Weber and Weber 1836; 1837; 1894, English transl. 1992). Subsequent empirical research has sought to explain

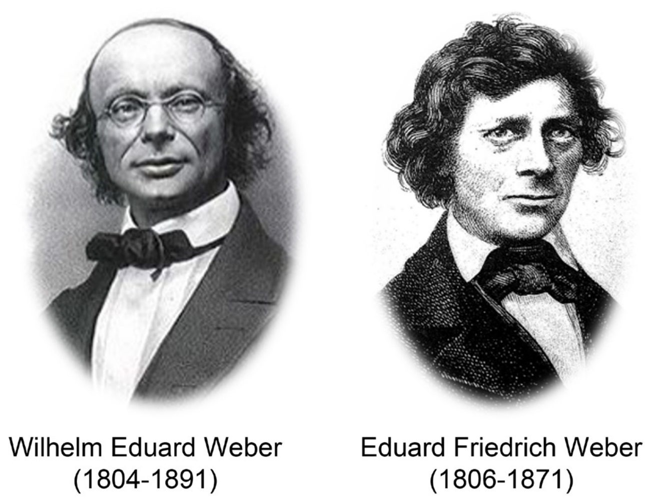

Figure 1. *The German physicist Wilhelm Eduard Weber (© Rudolph Hoffmann, Wikimedia Commons, public domain) and his brother, anatomist and physiologist Eduard Friedrich Weber (© William Sterling, Wikimedia Commons, CC BY 4.0).*

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this phenomenon, often referred to as the "hip fluid seal" (e.g., Dienst et al. 2002; Ferguson et al. 2000a; 2000b; 2003; Prietzel et al. 2007; Wingstrand et al. 1990). This literature was reviewed to better understand the factors that contribute to passive stabilization of the hip with the goal of minimizing use of force during hip dissection. Research objectives were to: 1) understand the factors contributing to passive stabilization of the hip against distractive forces, especially the so-called hip fluid seal; 2) apply this knowledge to minimize force required for hip disarticulation; and 3) formalize a hip dissection procedure based on strategic neutralization of the hip fluid seal.

Weber and Weber (1837): A Classic Experiment

Published in 1837, "On the mechanics of the human walking apparatus, with a description of an experiment on distraction of the femoral head from the acetabulum in a vacuum chamber" (Weber and Weber 1837) is a seminal early study of human hip biomechanics with an interesting backstory. Intrigued by the eminent scientist Alexander von Humboldt's observation that he experienced disproportionate lower-limb fatigue and disrupted gait while ascending Ecuador's Mount Chimborazo (elevation 6263 m, BBC Mundo 2016), Wilhelm and Eduard Weber designed an apparatus to investigate the effects of atmospheric pressure on hip stability (Weber and Weber 1836; 1837). Their landmark experiment demonstrated that subjecting an isolated cadaveric hip to vacuum would cause partial dislocation, which could then be reduced by restoration of atmospheric pressure. They discovered that drilling a hole through the acetabulum also caused spontaneous hip dislocation, even at normal atmosphere, presumably by neutralizing the pressure effect. Finally, the pressure effect alone was sufficient to prevent dislocation, even after removal of all capsular ligaments. The Webers hypothesized that atmospheric pressure somehow contributes to passive hip stabilization and that reduced pressure at high altitude necessitates compensatory recruitment of active hip stabilizers (e.g., lesser gluteal or lateral rotator muscles), leading to reduced locomotor efficiency and muscle fatigue (Weber and Weber 1836; 1837).

Modern Experimental Results

It was left to modern researchers to identify the anatomical and physical factors responsible for passive hip stabilization and to quantify their relationships. Consistent with the Webers' hypothesis, *in vivo* fluoroscopic studies of total hip arthroplasty patients have shown that during swing phase the human hip experiences inertial distraction forces that are not adequately compensated by dynamic hip stabilizers such as the hip rotator muscles (Komistek et al. 2002; Lombardi et al. 2000; Moore et al. 2018). Further studies have demonstrated that crucial passive stabilization to physiologic hip distraction is provided by the fibrous hip capsule, especially the zona orbicularis, and the acetabular labrum (Crawford et al. 2007; Dienst et al. 2002; Ferguson et al. 2003; Ito et al. 2009; Nepple et al. 2014). The spiral fibers of the hip capsule, and the iliofemoral ligament in particular (Figure 2a), draw the femoral head deeper into the acetabulum, providing stability in hip extension (Moore et al. 2018).

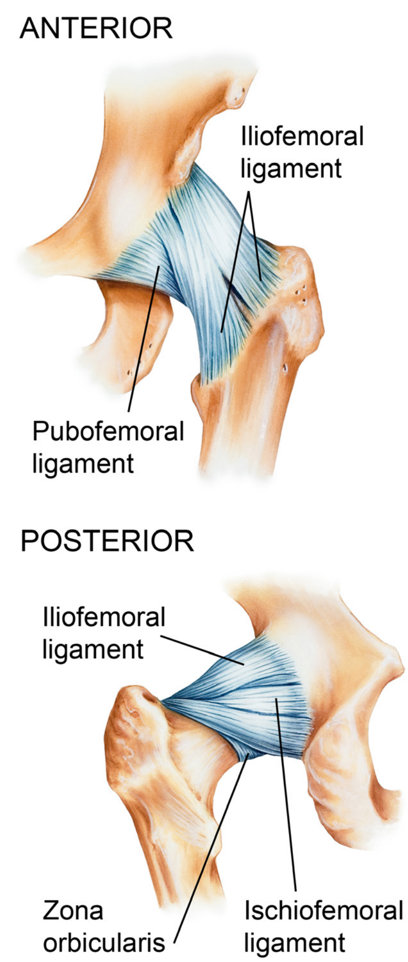

Figure 2. *Human hip with capsular ligaments intact: a) anterior view showing spiraling of the iliofemoral ligament; b) posterior view showing circular fibers of the zona orbicularis (illustrations © Shutterstock and Medical Art Inc.)*

By contrast, the circular fibers of the zona orbicularis (Figure 2b), which comprise the narrowest portion of the fibrous capsule, encircle the femoral neck to create a physical barrier to hip dislocation regardless of hip position (Ito et al. 2009). The zona orbicularis barrier comes into play as femoral distraction approaches 3 mm (Ito et al. 2009).

The acetabular labrum (Figures 3, 4d) has at least two functions related to hip stability. It effectively deepens the acetabulum, thus increasing surface area in contact with the

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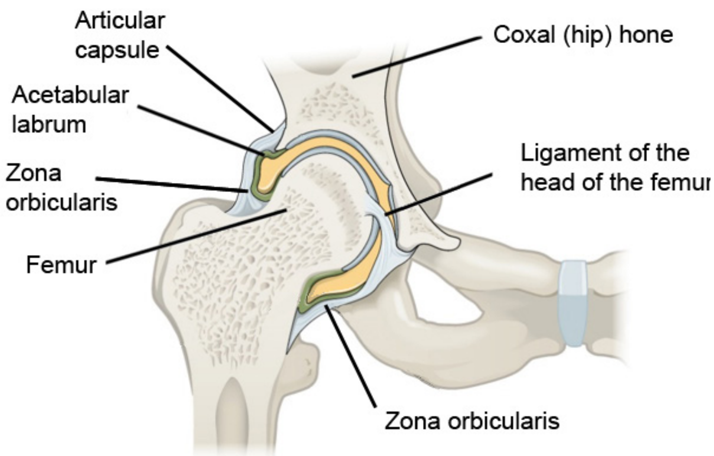

Figure 3. *Coronal section through the human hip illustrating the relationship of the femoral head to the acetabular labrum and zona orbicularis (© Open Stax College, CC BY 3.0).*

femoral head; however, its most important function appears to be maintenance of the hip fluid seal (Cadet et al. 2012; Ferguson et al. 2003; Nepple et al. 2014; Philippon et al. 2014). By retaining synovial fluid within the central compartment, the labrum enables pressurization in response to compressive loads (Crawford et al. 2007; Ferguson et al. 2003; Philippon et al. 2014). Synovial fluid pressurization distributes compressive forces uniformly, protecting the articular cartilage from excessive peak stresses (Ito et al. 2009). Conversely, the seal creates negative intra-articular pressure in response to distractive forces, the so-called suction effect (Crawford et al. 2007; Ferguson et al. 2003; Nepple et al. 2014). Experimental results have supported the importance of the suction effect to resistance against hip distraction and have further suggested that it operates most effectively in the range of 1–3 mm distraction (Dienst et al. 2002; Ito et al. 2009; Nepple et al. 2014).

As demonstrated by the Webers, the stabilizing effect of the hip fluid seal is dependent upon the differential between atmospheric pressure and intra-articular pressure. According to Wingstrand et al. (1990), the theoretical distractive force *F* required to overcome the stabilizing effect of atmospheric pressure is calculated as $F = \frac{\pi D^2}{4} * (P_a\text{-}P_i)$ where D = femoral head diameter (m), P_a = atmospheric pressure (N/m^2), and P_i = saturated vapor pressure (N/m^2) of synovial fluid at 37ºC, i.e., intra-articular pressure. It is apparent from this equation that, holding $(P_a\text{-}P_i)$ constant, distractive force is directly proportional to the cross-sectional area of the femoral head (Prietzel et al. 2014; Wingstrand et al. 1990). However, it is also apparent that as the pressure differential $(P_a\text{-}P_i)$ decreases, *F* goes to zero, irrespective of femur size. Accordingly, in the absence of a pressure differential, the suction effect is

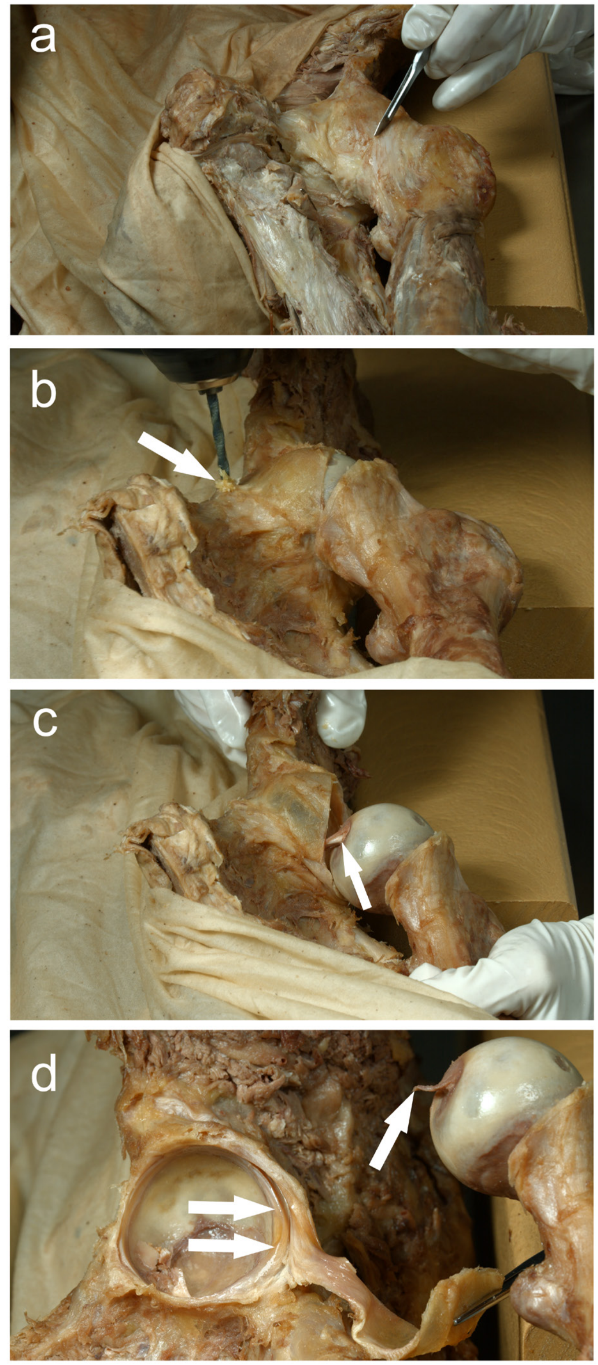

Figure 4. *Hip dissection using the Weber drill technique: a) incision of fibrous hip capsule (left hip, anterior view); b) placement of drill hole (white arrow) between the anterior inferior iliac spine and acetabular notch; c) disarticulation with the ligament of the head of the femur (white arrow) intact; d) completed joint dissection showing the severed ligament (single arrow) and acetabular labrum (double arrow) (Photos courtesy of Midwestern University Media Services Department; © 2017 Department of Anatomy).*

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nullified and, in theory, the only resistance to hip dislocation is provided by ligaments and muscles uniting the pelvis and femur.

The absolute force required to overcome the suction effect of the hip fluid seal can be considerable. Modern attempts to measure the required distraction force have yielded values ranging from 124–150 N (Nepple et al. 2014), remarkably similar to Weber and Weber's estimate of ~120 N (1836, 1837). Because necessary distraction force is so high, it is standard practice in hip arthroscopy to "vent" the fluid seal by introducing air or saline solution to the central compartment to reduce necessary traction force and risk of iatrogenic nerve injury (Dienst et al. 2002). While authors disagree as to the preferred method, strategic venting of the hip fluid seal has proven valuable in the operating theater (Dienst et al. 2002). This study sought to determine if it is similarly useful in the context of anatomical dissection.

Materials and Methods

Materials

The anatomical donors utilized in this study were obtained from the Anatomical Gift Association of Illinois, which was responsible for donor or family consent, embalming, and donor maintenance prior to delivery to Midwestern University (Downers Grove, IL). Under the United States Code of Federal Regulations (HHS 2019), anonymous anatomical donor research does not meet the regulatory definition of human subjects research. This study was approved as such by the Midwestern University Institutional Review Board and was conducted in compliance with Midwestern University Anatomy Laboratory policies for human anatomical research. The Anatomical Gift Association obtained informed consent from all donors.

Hips were sampled opportunistically from donors allocated to medical and allied health anatomy courses during academic years 2016–2018. Donors were chosen on the basis of low adiposity, hip mobility, and absence of evidence of hip arthroplasty. Donors discovered to have severe pathology (e.g., femoral osteonecrosis) or artificial hip implants were excluded. The final donor sample comprised 5 males and 11 females ranging from 62 to 96 years of age. Consistent with U.S. health trends for older adults (CDC 2017), the most common causes of death were cancer (N=6) and cardiovascular disease (N=3). Four deaths were attributable to COPD, malnutrition, subdural hematoma, and sepsis, respectively, while the remaining donor deaths (N=3) were attributed to nonspecific causes such as "respiratory arrest." Dissections were performed in the Michael B. Tierney, D.O. Anatomy Laboratory of Midwestern University.

Dissection Methods

A total of 16 hip dissections were performed by the authors and by anatomy students under the supervision of the corresponding author and laboratory staff. All dissections were performed unilaterally on cadavers with hemisected pelves. Dissections followed the sequence outlined in *Grant's Dissector,* 16th ed. (Detton 2017), including reflection or removal of rectus femoris, pectineus, iliopsoas, and tensor fasciae latae anteriorly, and the gluteal muscles and lateral rotators (piriformis, obturator internus and externus, superior and inferior gemellus, and quadratus femoris) posteriorly. Following complete incision of the fibrous hip capsule (Figure 4a, Supplemental Video) (Detton 2017, Figures 6.33-34), the strength of the hip fluid seal was evaluated by manually fixing the hemipelvis and attempting to distract the femoral head laterally (Supplemental Video). Distractive forces were applied to the proximal femoral shaft immediately inferior to the femoral neck with the hip in neutral position. In all cases, the hip fluid seal prevented dislocation, and in most cases, resistance to distraction was perceived by the examiner as strong. After establishing the integrity of the hip seal, a new step was introduced to the dissection sequence.

The Weber Drill Technique

Following the example of Weber and Weber (1836, 1837), a 3 mm diameter hole was drilled in the acetabular rim approximately 2 cm superior to the acetabular notch and just below the anterior inferior iliac spine (Figure 4b, Supplemental Video). The drill-hole site was selected for ease of access, proximity to readily identifiable landmarks, and to avoid damage to the ligament of the femoral head (ligamentum teres femoris). Initial trials (N=2) used a manual rotary drill, whereas later trials used a Black and Decker™ cordless drill (Model LDX172). The drill was advanced until synovial fluid was expressed from the drill hole. Due to the narrowness of the hip joint space, the drill bit frequently entered the femoral head; however, the resulting femoral damage was minimal. As described above, lateral distractive forces were again applied to dislocate the femoral head (Figure 4c), exposing the ligament of the head of the femur. This ligament was then severed to complete the disarticulation (Figure 4d).

Results and Discussion

Results

After drilling the acetabulum, resistance to femur distraction decreased relative to the undrilled state. In most cases, the femoral head slid easily from the acetabulum without resort to force or leverage maneuvers (Figure 4c); however, some variation in ease of dislocation was observed.

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The Hip Fluid Seal
This communication summarizes present understanding of the stabilizing effect of the hip fluid seal and describes a practical application of this knowledge to anatomical dissection. The suction effect of the hip fluid seal is a physical phenomenon that stabilizes the hip against distractive forces (Crawford et al. 2007; Nepple et al. 2014). As demonstrated by Wingstrand et al.'s equation, the force required to overcome the seal is a function of both femoral head size and the pressure differential across the articular capsule (Wingstrand et al. 1990). This relationship has interesting implications for individual variation in hip stability. Because distractive force is proportional to femoral head size, greater force should be required to dislocate hips of larger versus smaller individuals. Since head diameter is among the most dimorphic femur dimensions (Boldsen et al. 2015; Dwight 1905; Parsons 1915; Steele and Bramblett 1988; Thieme and Schull 1957), other factors being equal, greater force should be required to dislocate the hips of males versus females. On the other hand, a recent study of U.S. residents found females to have deeper acetabula relative to femur head diameter (Wang et al. 2004), which might increase effective head area and enhance hip stability relative to males with equivalent femoral head dimensions. These hypotheses have direct bearing on hip function and the relative frequency of hip pathologies and thus merit further investigation.

In the context of anatomical dissection, understanding the relationship of femoral head size to distraction force may aid selection of donors for prosection; however, in most labs donor choice is limited. While femoral head area is fixed for a given donor, the differential between atmospheric and intra-articular pressure is subject to manipulation. Equilibration of pressures across the joint capsule should aid disarticulation irrespective of donor characteristics such as sex and size.

Weber Drill Dissection Technique
This report describes an approach to hip dissection based on strategic release of the hip fluid seal. While our results are qualitative, they suggest the drill-hole technique, adapted from the experiments of Weber and Weber (1836, 1837), reduces the pressure differential that contributes to passive stabilization of the hip against distractive forces. By reducing distraction force, the Weber drill procedure potentially facilitates hip disarticulation and minimizes the risk of fracture or damage to structures such as the acetabular labrum. Consequently, this technique could provide anatomy faculty and students with a less stressful dissection experience, as well as the opportunity to directly observe the interplay of factors contributing to normal human hip function. Anecdotally, the added "gee-whiz" factor of this approach appears to increase student engagement, which is linked to positive educational outcomes (Carini et al. 2006). Finally, the Weber drill procedure requires minimal faculty supervision, is simple to implement, and uses inexpensive tools, making it accessible to any institution. It is the authors' hope that disseminating knowledge of this approach and its scientific rationale will enhance student understanding of human hip structure and biomechanics.

Study Limitations

The principal objective of this study was to develop an alternative hip dissection method founded in basic principles of hip biomechanics. Owing to limited donor choice and narrow windows for dissection, the sample is small and is not controlled for biological sex or donor age. Study results are admittedly qualitative, and not all donor hips demonstrated reduced distraction force post-drilling. These cases potentially reflect individual variation in hip form and/or the presence of subclinical pathologies affecting hip seal strength and integrity. Further quantitative studies of the drill method's efficacy and pedagogical value are desirable.

Conclusions

Inspired by an early nineteenth-century experiment, the Weber drill technique is a simple, inexpensive method of hip dissection based on strategic venting of the hip fluid seal. This method facilitates disarticulation and allows students to directly observe the effects of physical factors such as atmospheric pressure that contribute to passive stabilization of the human hip.

Acknowledgments

This study is dedicated to the memory of the late Stephen Sears, Midwestern University Anatomical Laboratory Manager, 1990–2017. The authors thank Stephen Sears, Sally Jo Detloff, and Tamia Pasley (Michael B. Tierney, D.O., Anatomy Laboratory) for logistical support; Mackenzie Loyet and Julie Doll (MWU Department of Anatomy) for photographic and laboratory assistance; Paul Lyzun, Jason Huls, and Molly Gardner (MWU Department of Media Services) for videography and editing; Daniel E. Ehrlich, Kathryn Eggert, and Joseph R. Krecioch (Department of Anatomy) for figure production and editing; CCOM 2019 students Karlee Kirkpatrick and Stephen Simeone for assistance during video production; and Dr. Kerry Hull, Dr. Wojciech Pawlina, and several anonymous reviewers for their constructive comments.

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Literature Cited

BBC Mundo. Chimborazo, el volcán de Ecuador más alto que el Everest (si se mide desde el centro de la Tierra). 2016. London, UK: BBC World Service; [cited 2019 Jan 20]. Available from: https://www.bbc.com/mundo/noticias/2016/04/160407_por_que_chimborazo_ecuador_mas_lejos_centro_tierra_que_el_everest_dgm.

Boldsen JL, Milner GR, Boldsen SK. 2015. Brief communication: Sex estimation from modern American humeri and femora, accounting for sample variance structure. *Am J Phys Anthropol* 158:745-750.

Cadet E, Chan A, Vorys G, Gardner T, Yin B. 2012. Investigation of the preservation of the fluid seal effect in the repaired, partially resected, and reconstructed acetabular labrum in a cadaveric hip model. *Am J Sports Med* 40(10):2218-2223.

Carini RM, Kuh GD, Klein SP. 2006. Student engagement and student learning: Testing the linkages. *Res High Educ* 47(1):1-32.

CDC. Table 20. Leading causes of death and numbers of deaths, by age: United States, 1980 and 2016. 2017. Atlanta, GA: Centers for Disease Control and Prevention; [cited 2019 Jan 15]. Available from: https://www.cdc.gov/nchs/data/hus/2017/020.pdf.

Crawford M, Dy C, Alexander J, Thompson M, Schroder S, Vega C, Patel R, Miller A, McCarthy J, Lowe W et al. 2007. Frank Stinchfield award. The biomechanics of the hip labrum and the stability of the hip. *Clin Orthop Relat Res* 465:16-22.

Detton AJ. 2017. Grant's dissector, 16th edition. New York (NY): Wolters Kluwer.

Dienst M, Seil R, Gödde S, Brang M, Becker K, Georg T, Kohn D. 2002. Effects of traction, distension, and joint position on distraction of the hip joint: An experimental study in cadavers. *Arthroscopy* 18(8):865-871.

Dwight T. 1905. The size of the articular surfaces of the long bones as characteristic of sex; an anthropological study. *Am J Anat* 4:19-32.

Ferguson S, Bryant J, Ganz R, Ito K. 2000a. The acetabular labrum seal: A poroelastic finite element model. *Clin Biomech* 15(6):463-468.

Ferguson S, Bryant J, Ganz R, Ito K. 2000b. The influence of the acetabular labrum on hip joint cartilage consolidation: a poroelastic finite element model. *J Biomech* 33(8):953-960.

Ferguson S, Bryant J, Ganz R, Ito K. 2003. An in vitro investigation of the acetabular labral seal in hip joint mechanics. *J Biomech* 36(2):171-178.

HHS. 2019. Protection of human subjects, 45 C.F.R. §46.102–104.

Ito H, Song Y, Lindsey D, Safran M, Giori N. 2009. The proximal hip joint capsule and the zona orbicularis contribute to hip joint stability in distraction. *J Orthopaed Res* 27(8):989-995.

Komistek R, Dennis D, Ochoa J. 2002. In vivo comparison of hip separation after metal-on-metal or metal-on-polyethylene total hip arthroplasty. *J Bone Joint Surg Am* 84:1836-1841.

Lombardi AJ, Mallory T, Dennis D. 2000. An in vivo determination of total hip arthroplasty pistoning during activity. *J Arthroplast* 15:702-709.

Moore KL, Dalley AF, Agur AM. 2018. Clinically oriented anatomy, 8th edition. New York, NY: Wolters Kluwer.

Nepple J, Philippon M, Campbell K, Dornan G, Jansson K, LaPrade R, Wijdicks C. 2014. The hip fluid seal-Part II: The effect of an acetabular labral tear, repair, resection, and reconstruction on hip stability to distraction. *Knee Surg Sports Traumatol Arthrosc* 22(4):730-736.

Parsons F. 1915. The characters of the English thigh-bone. Part II.: The difficulty of sexing. J *Anat Physiol* 49(4):345-361.

Philippon M, Nepple J, Campbell K, Dornan G, Jansson K, LaPrade R, Wijdicks C. 2014. The hip fluid seal-Part I: The effect of an acetabular labral tear, repair, resection, and reconstruction on hip fluid pressurization. *Knee Surg Sports Traumatol Arthrosc* 22(4):722-729.

Prietzel T, Hammer N, Schleifenbaum S, Kaßebaum E, Farag M, von Salis-Soglio G. 2014. On the permanent hip-stabilizing effect of atmospheric pressure. *J Biomech* 47(11):2660-2665.

Prietzel T, Richter K, Pilz D, von Salis-Soglio G. 2007. The stabilizing effect of atmospheric pressure (AP) on hip joint subject to traction force--an experimental study. *Z Orthop Unfall* 145(4):468-475.

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Steele DG, Bramblett CA. 1988. The anatomy and biology of the human skeleton, 1st edition. College Station (TX): Texas A&M University Press.

Thieme FP, Schull WJ. 1957. Sex determination from the skeleton. *Hum Biol* 29(3):242-273.

Wang SC, Brede C, Lange D, Poster CS, Lange AW, Kohoyda-Inglis C, Sochor MR, Ipaktchi K, Rowe SA, Patel S et al. 2004. Gender differences in hip anatomy: Possible implications for injury tolerance in frontal collisions. *Annu Proc Assoc Adv Automot Med* 48:287-301.

Weber WE, Weber EF. 1836. Mechanik der menschlichen Gehwerkzeuge: Eine anatomisch-physiologisch Untersuchung nebst einem Hefte mit 17 Tafeln anatomischer Abbildungen. Göttingen, Germany: Dieterichschen Buchhandlung.

Weber WE, Weber EF. 1837. Ueber die Mechanik der menschlichen Gehwerkzeuge, nebst der Beschreibung eines Versuchs über das Herausfallen des Schenkelkopfs aus der Pfanne im luftverdünnten Raume. *Annal Phys Chem* 40(1):1-13.

Weber WE, Weber EF. 1992. Mechanics of the human walking apparatus [Mechanik der menschlichen Gehwerkzeuge]. (Maquet P, Furlong R, Trans.). Berlin, Germany: Springer-Verlag. (Original work published 1894).

Wingstrand H, Wingstrand A, Krantz P. 1990. Intracapsular and atmospheric pressure in the dynamics and stability of the hip: A biomechanical study. *Orthopaed Scand* 61(3):231-235.

Supplemental Video.

Sixty-second video summarizing the rationale and execution of the Weber drill procedure for human hip dissection (© 2017 Midwestern University Department of Anatomy).
https://youtu.be/15PFG4OFq5M

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An Outreach Activity Teaching Cub Scouts About the Human Body

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Abstract
Possessing awareness about the human body is important for the maintenance of good health. To increase such awareness in children's daily lives, we developed and implemented a two-hour activity session for a group of nine Cub Scouts. Three graduate students, one undergraduate student, and one high school student assisted faculty during this session. The children were given a presentation about the human body using an Anatomage Table and models of the heart, lungs, liver, kidney, muscle, and ear. The Cub Scouts were given a brief quiz before and after the session in order to evaluate the impact of the intervention on students' knowledge. The post-test score was 8% higher than the pre-test score ($p<0.05$), suggesting that the introduction to the human body was helpful in enhancing Cub Scouts' learning. This project also allowed high school, undergraduate, and graduate students to communicate anatomy with young children at their level. https://doi.org/10.21692/haps.2020.008

Key words: Cub Scouts, human body, The Anatomage Table

Introduction
Outreach is a meaningful teaching service that benefits the public beyond the academic community (Andrews et al. 2005). Public outreach is a powerful and immediate means of bridging formal and informal science education (Stocklmayer et al. 2010). Science outreach may include tutoring, mentoring, presentations, facilitating inquiry, supporting teachers during school, after school and in summer programs, judging science fairs, and developing resources and curricula. Educational outreach activities for children between the ages of five and 18 years old (K–12) are a direct way of increasing young students' scientific knowledge and skills, and fostering their interest in science. Physiology Understanding (PhUn) Week is an outreach program sponsored by the American Physiological Society (APS) that brings physiologists and K-12 students together to introduce laypersons to concepts related to physiology (Stieben et al. 2017).

Engaging undergraduate, graduate, and high school students in outreach activities helps students develop leadership and communication skills especially in translating difficult scientific concepts into simple terms that the younger learners are able to understand. In addition, presentations regarding technical topics often lead to many questions from students, and having graduate students and research scientists directly involved in K-12 educational programs can help address this issue (Clark et al. 2016).

As an outreach activity to stimulate young minds, this project consisted of two goals. Inspiring students in science was the primary goal. We introduced the details of the human body to the Cub Scouts as a hands-on activity through a number of models as well as using the Anatomage Table, which is a visualization system of radiologic images of human cadavers (Custer and Michael 2015). Pre- and post-tests were used to measure changes in student knowledge. The second purpose of this study was to provide opportunities for older students (one high school, one undergraduate, and three graduates) to utilize their knowledge of the human body to design relevant educational experiences for the youth. Any additional gains from organizing this event by the student volunteers were revealed using a qualitative survey.

Materials and Methods
Recruitment
The Institutional Review Board (IRB) of the Southern Illinois University, Edwardsville (SIUE), approved this project, IRB protocol #172. Youths, ages five to ten years, from a Cub Scout pack in Edwardsville, Illinois were invited to participate in an evening of learning about the human body. Parents or guardians and youth provided consent and assent, respectively.

Event Description
A two-hour session was held at SIUE during PhUn week in 2018. Models of specific organs were displayed, one per table, in a common area and the Anatomage Table was located in the simulation lab. First, the students were given a pre-test followed by hands-on activities and a post-test at the very end of the session. The pre-test consisted of a total of ten questions, nine multiple choice and one true/false question (Figure 6). Once the pre-test was completed, students were put into random groups of two to three participants per group and directed to stations that contained three-dimensional models for specific human organs (the lungs, liver, heart, kidney, ear, and muscle). Each station was staffed by a volunteer (student or faculty) who explained the structure

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***Figure 1**. A Cub Scout Listening to the Stethoscope as the volunteer assisted.*

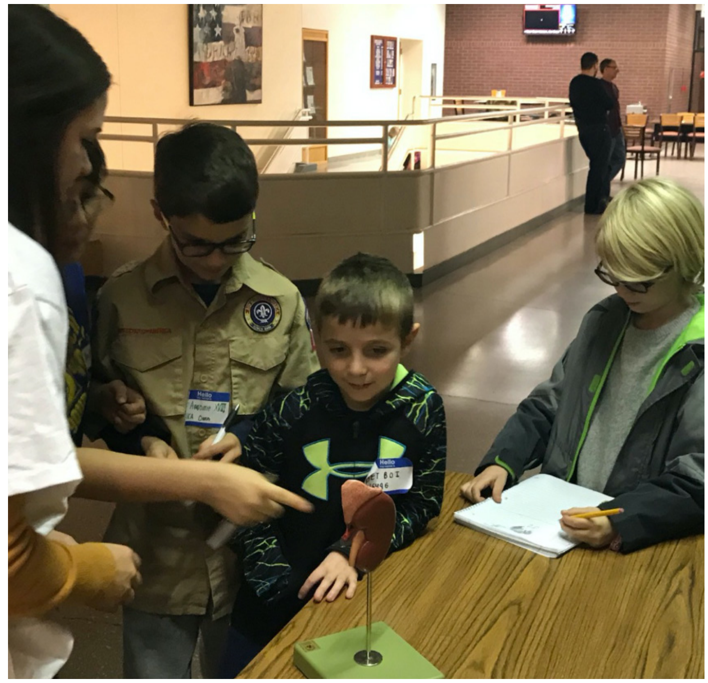

***Figure 2**. Cub Scouts Exploring the Kidney Model. A volunteer is explaining details of where urine is made and how it travels within the kidney and then into the ureter.*

***Figure 3**. Cub Scouts Exploring the Muscle Model with the assistance of a volunteer. The muscles could be taken apart and reassembled. A volunteer assisted participants to name a few muscles and explained the functions of muscles in general.*

***Figure 4**. Cub Scouts Exploring the Lungs Model. A volunteer helped the group learn about the lobes of the lungs, bronchial tree and the functions of the lungs.*

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***Figure 5**. Cub Scouts Exploring the Liver Model. The functions of the liver, the lobes of the liver and the gallbladder were discussed at this station.*

and function(s) of the organ in very simple terms, appropriate for the ages of the Scouts, who ranged in age from five to ten years. The volunteers also explained the locations of these organs within the body as well as their relationships to the overall body function. Examples, analogies, and disease states were used to explain the concepts.

Hands on activities included the opportunity for the Cub Scouts to listen to their own heart sounds using a stethoscope (Figure 1). The Scouts spent approximately ten minutes at each station, allowing ample time to interact with the models, including dismantling and rebuilding them, as well as asking questions. After each Scout visited all stations, student volunteers provided an interactive presentation using the Anatomage Table. They were able to touch the Anatomage screen to point to the organs that were displayed. After studying each model and the Anatomage Table, the Scouts completed the post-test, which was the same as the pre-test so that learning gains could be assessed.

Volunteers

The volunteers consisted of a high school student, an undergraduate student, and three graduate students as well as two faculty members. The students were teaching and research assistants with the two faculty mentors involved in the PhUn project. All of the volunteers were familiar with the human body since they had completed advanced placement Biology (high school student) or Anatomy and Physiology courses (undergraduate and graduate students). Each volunteer assumed responsibilities in one or more activities such as composing the questionnaire and the answer key, demonstrating body parts using the Anatomage Table, proctoring pre- and post-tests, setting up and staffing of the tables with models, and interacting with groups of Scouts as they visited each table. Volunteers practiced the presentation of details pertaining to each model with at least one faculty member prior to the event and revised their scripts as needed.

Anatomage Table and the Models

The Anatomage Table is an advanced anatomy visualization system that is built utilizing radiographic images of cadavers. It allows dissection of the human body in any angle. It is an excellent device for hands-on and interactive methods to understand cross- sectional anatomy of body parts and adjacent structures associated in an integrative approach. It also allows the visualization of blood vessel arrangements, lymphatics, and nerve supply to the selected body parts. The three-dimensional models for specific human organs (the lungs, liver, heart, kidney, ear, and muscle) can be disassembled to explore deeper parts. The ability to remove and rearrange the parts of each model itself can intrigue users to engage with the body parts (Figures 2 to 5). Having an opportunity to touch and view the organs on the Anatomage Table screen in detail was another interactive mode for students to learn about the body parts.

Assessment

The pre- and post-tests consisted of the same ten questions and assessed Scouts' knowledge of body structures and functions (Figure 6). Use of the same questions for the pre-test and post-test allowed for assessment of how the learning activities enhanced the Scouts' knowledge on general anatomy and physiology topics.

Nine of the Cub Scouts were accompanied by their parents. The Scouts completed the pre-test, some receiving help from their parents to read the questions. In the case of a word/words that a Scout did not understand, a brief explanation was provided. Parents were asked not to provide any hints or reveal answers while reading questions. After both tests were completed, student volunteers graded the Scouts' pre-test and post-tests. Leadership experience by the student volunteers were assessed through virtual individual interviews following the event.

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Statistical Analysis
A paired Student t-test was used to analyze the data from both the pre-test and the post-test using the *Graphpad Prism* program. Student volunteer survey responses were analyzed qualitatively as described below.

Results

Results are summarized in Figures 7, 8, and 9. As shown in Figure 7, there was an average of 8% increase in knowledge from the pre-test to the post-test ($p<0.05$), which signifies an overall improvement due to a variety of learning activities. Figure 8 shows that, although not statistically significant, all the Scouts except for Scout 2 had improved in comparison to their pre-test results. As displayed in Figure 9, though not statistically significant, the Scouts had the most improvement in knowledge related to the liver. Figure 9 also shows that while, again not statistically significant, the Scouts' knowledge was reduced in post-test questions related to the heart and lungs.

1. What is the Heart made up of?
    1. Muscle
    2. Bones
    3. Cartilage
    4. Skin
2. How many bones are in your ear?
    1. 1
    2. 2
    3. 3
    4. 4
3. The lungs help to add ______ to the blood
    1. Air
    2. Oxygen
    3. Carbon Dioxide
    4. Nitrogen
4. What is one function of the liver?
    1. Supplies blood throughout the body
    2. Helps absorb energy from the body
    3. Helps detoxify the blood
    4. Circulates vitamins in the body
5. What is a byproduct of the kidney?
    1. Blood
    2. Urine
    3. Protein
    4. Fat
6. If you do not use your muscles, what happens to them?
    1. They strengthen
    2. Nothing
    3. They weaken
    4. They will grow
7. Eating a lot of salty foods will not affect your heart
    1. True
    2. False
8. How can one survive without any kidneys?
    1. They can't
    2. A Dialysis machine
    3. Eating less food
    4. Drinking only water
9. What is a lung made up of?
    1. Neurons
    2. Bronchioles
    3. Capillaries
    4. Rods and Cones
10. Which one these is **not** a type of muscle?
    1. Smooth Muscle
    2. Straight Muscle
    3. Skeletal Muscle
    4. Cardiac Muscle

Figure 6. *Questionnaire Used as Pre-Test/Post-Test. There were 10 questions in total, 9 multiple choice and one true-false. The same questions were used in both pre-and post-tests.*

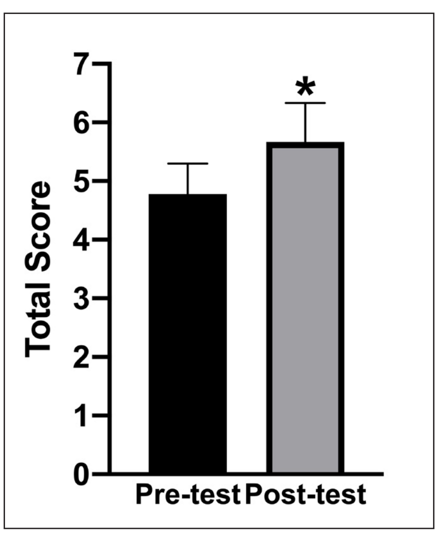

Figure 7*. Mean scores of Pre-test and Post-test of the Cub Scout Group *P<0.05 (N=9).*

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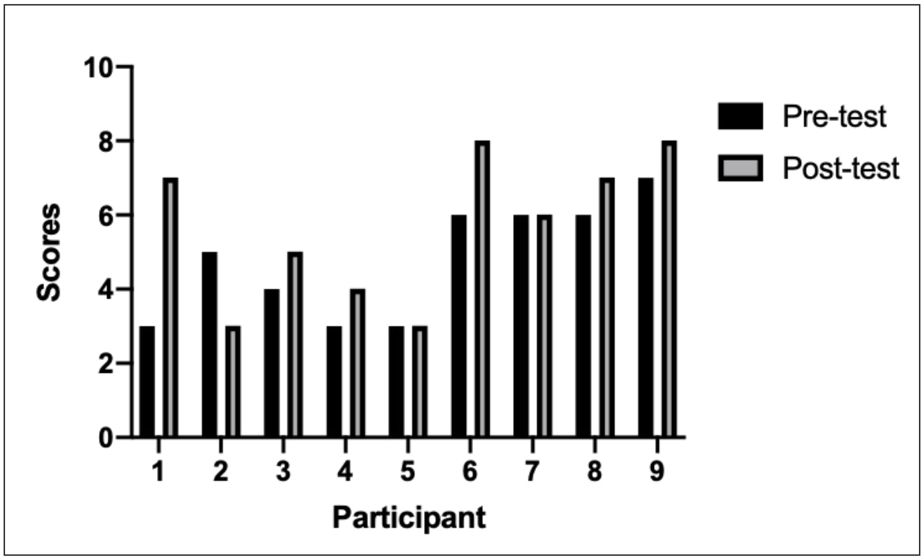

Figure 8. *Comparison of Pre- and Post-test Scores of Individual Participants (N=9).*

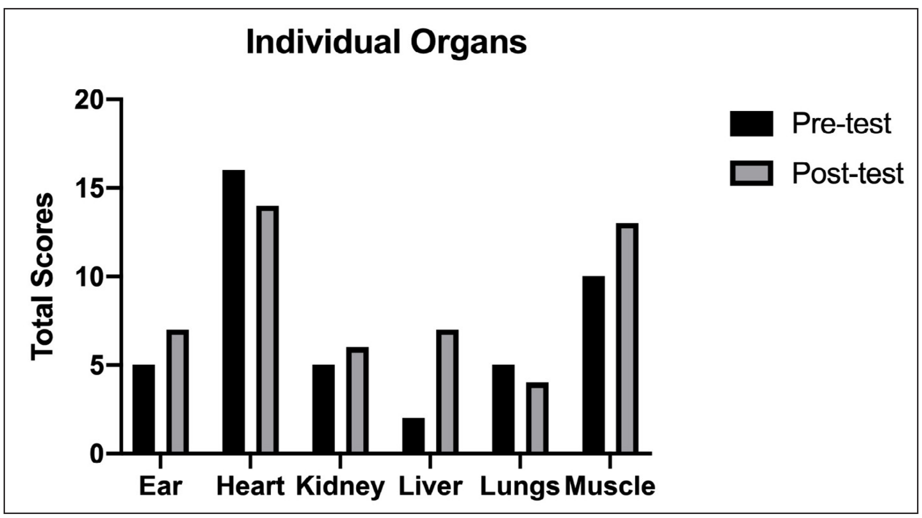

Figure 9. *Comparison of Pre- and Post-test Scores by Individual Organs (N=9).*

Another outcome assessed in this study was the benefit student volunteers experienced from participating in the project. Five student volunteers participated in this project, four of which submitted survey responses following the event. Based on their responses, the leadership roles can be broken down into two categories: 1) tasks or roles assigned as part of the project, and 2) serving as an effective teacher for the Scouts.

The roles and responsibilities for each student volunteer were slightly different, partially due to their educational level and work experience. For instance, the graduate students held more responsibility in the event than the undergraduate and high school students. Each student volunteer held a leadership role in that they were each responsible for teaching about a particular organ. Additionally, the graduate students were responsible for creating the lesson plan, preparing and introducing "…the Anatomage table teaching components...", and developing the pre- and post-tests.

The student volunteers felt that they were able to effectively teach about their assigned organ in layman terms, particularly in terms that young children could understand. Each student volunteer prepared for the event in their own way, from "… researching and reading over the importance…" of the organ they were responsible for teaching about, to relying on "…my prior physiology knowledge from an AP Biology class…." The

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two graduate students both had previous work experience in clinical pediatric settings and so, were especially familiar with effective ways to convey complex health information in understandable terms. Techniques described included analogies, "…open ended questions to get a baseline knowledge level," and stopping "…to ensure that the students [understood] the general idea of what I was saying" prior to providing additional explanations. Further, the student volunteers found that as the event went on, they became progressively better and improved "…their own skills about explaining complex information clearly and in simple words and phrase."

Discussion

Our study to engage Cub Scouts using hands-on activities was successful as evidenced by a significant increase in their post-test performance. The improvement of scores with the liver questions was greater than with most other organs. This is possibly due to the students' very little knowledge about the liver prior to attending this session. These results also suggest that the student volunteers were able to communicate with the Scouts effectively which helped the young learners have a positive experience. Besides staffing the table with models, student volunteers also were able to help plan the entire event, demonstrating an important aspect in leadership skills. The student volunteers set up a station for each model, created pre- and the post-tests, proctored the assessments, explained the details of the models at the most basic level possible, and demonstrated the body parts using the Anatomage Table while also asking and answering questions from the Scouts.

One of the constraints of the study was that the assessment was limited to pre- and post-tests of a multiple-choice test style. The questions seemed appropriate to us as college students and researchers, but it would have been helpful to evaluate the literacy level. The Scouts ranged in age from five to ten years, which challenged the student volunteers and faculty members to be very sure that every participant understood the questions and the details of the organs that were discussed. This aspect was addressed by using many examples and analogies to explain and describe the organs. Another constraint was the small sample size consisting of only nine Scouts from one Cub Scout Pack. This was partly due to the busy schedules of many parents and the Cub Scouts themselves. It was difficult to find additional Packs that had enough time to participate in this study.

Student volunteers not only led the activities successfully, but also were able to explain complex details in simplified terms to the younger audience. A short survey conducted to gain insight into the student volunteers' experience suggested that they enjoyed being part of this event as it provided them an opportunity to interact with the young Cub Scouts and share knowledge with them.

Based on the limitations, there are many adjustments that might be made in the future that could be helpful. For example, a discussion format could be implemented for the pre-test and the post-test in order to allow for a better understanding of what children learned from the activities. Parents and guardians could be involved as well in order to help the youth participants understand the questions in the discussion. In addition, a follow-up test a few months after the study could be added to the protocol in order to determine any long-term knowledge that the youth retained from the study. Plans are under way to assess the long-term benefit of the learning activities to the students and to determine if a decline in knowledge occurred over time.

Conclusions

In our present study, providing students with an opportunity to learn about the human body in an interactive manner enhanced learning about the subject. Most of the Cub Scouts were very engaged and proactive in the discussions throughout the activities (Figures 1-5). Learning about the human body by using models and the Anatomage Table may help encourage youth to pursue careers in areas of health sciences. At the same time, this program provided a structure for graduate, undergraduate, and high school student volunteers to gain experience in interacting and explaining complex topics clearly to their community. One of the benefits of this program is the minimal time investment required from both the participants and the volunteers in order to yield very positive results.

Acknowledgments

We would like to thank the undergraduate and graduate students at SIUE for their enthusiastic presentation and the Cub Scouts for participating eagerly in the study. We also thank the parents for their support in bringing the children to participate in this project.

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Literature Cited

Andrews E, Weaver A, Hanley D, Shamatha J, Melton G. 2005. Scientists and Public Outreach: Participation, Motivations, and Impediments. *J Geosci Educ* 53 doi: 10.5408/1089-9995-53.3.281

Clark G, Russell J, Enyeart P, Gracia P, Wessel A, Jarmoskaite I, Polioudakis D, Stuart Y, Gonzalez T, MacKrell A, Rodenbusch S, Stovall G, Beckham J, Montgomery M, Tasneem T, Jones J, Simmons S, Stanley R. 2016. Science Educational Outreach Programs That Benefit Students and Scientists. PLoS Biol 14(2). doi: 10.1371/journal.pbio.1002368

Custer M, Michael K. 2015.The Utilization of the Anatomage Virtual Dissection Table in the Education of Imaging Science Students. *J Tomography & Simulation* 1. doi: 10.4172/jts.1000102

Stieben M, Halpin P, Matyas M. 2017. Developing a nationwide K–12 outreach model: Physiology Understanding (PhUn) Week 10 years later. *Am J of Physiol* 41: 357-362. doi: 10.1152/advan.00005.2017.

Stocklmayer S, Rennie L, Gilbert J. 2010. The roles of the formal and informal sectors in the provision of effective science education. *Studies in Sci Educ* 1. doi: 10.1080/03057260903562284

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Incentivizing Students to Encourage Consistent Study Group Attendance is Associated with Improved Course Performance

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Abstract
Human Anatomy and Physiology I is a rigorous course where developing strong study habits poses a challenge that many students have difficulty overcoming. In an attempt to help students better prepare for exams and improve their overall performance, we introduced incentives for participating in study groups. Here we examine the possible impact these study groups had on exam and course grades of students who participated in study groups versus those who did not, as well as the students' overall attitudes on incorporating these groups into their study habits. Students reported that participation in study groups was a positive experience that helped keep them on track with their material as well as aiding them in preparing for exams. Our goal was to help students develop good study habits that will set them on a path to success in their subsequent coursework. In addition, we anticipated that students would recognize the value of working in groups and strengthen their learning networks and sense of learning community. https://doi.org/10.21692/haps.2020.008

Key words: study groups, study habits, student performance

Introduction
Human Anatomy and Physiology I, a course geared towards first-year nursing and health professions students, is a rigorous course that historically has been a struggle for many students. Nationally, approximately 30 percent of students enrolled in introductory anatomy and physiology courses withdraw or receive a grade below C (Harris et al. 2004), with some institutions reporting as high as 50% of the students receiving a grade below C (Hull et al. 2016; Sturges and Maurer 2013). As at many institutions, many of our students come into the course having never taken a college level science course and have yet to develop the study habits needed to succeed in a course of this breadth and depth (Gultice et al. 2015). Learning a great deal of new material poses a challenge that many students have difficulty overcoming. This challenge is compounded by the fact that students must also simultaneously develop the strong study habits essential to academic success (Sebesta and Bray Speth 2017). Acknowledging that our students face these hurdles, we began to explore ways to assist our students in the process of developing their study habits.

Effective studying must be strategic, incorporating multiple tactics. Previous studies have shown that the amount of time spent studying does not always directly impact the performance of the student; rather the specific study habits of students have a greater impact on student success (Nonis and Hudson 2010). Deliberate practices, such as planning specific and consistent times for studying, have been shown to have a higher impact on improving student success than the number of hours dedicated to studying (Plant et al. 2005). Successful approaches to studying should be supplemented by a strong learning community, as part of a framework to improve STEM student persistence (Graham et al. 2013).

A learning community has been described as an intentional practice of creating environments for students that foster relationships among peers with the hopes of enhancing the learning experience (Smith et al. 2004). Students interacting with their peers inside and outside of the classroom has the benefit of exposing them to various styles and techniques utilized in the learning process (Light and Micari 2013), while also increasing their sense of belonging to the learning community (Strayhorn 2019; Lewis et al. 2016). A mechanism for fostering this peer interaction with an academic focus is course-based study groups (Guenther et al. 2019; Sandoval-Lucero et al. 2012). Establishing learning communities, including the incorporation of study groups as part of these learning communities, has been shown to lead to increased persistence and overall better sense of belonging in students who were a part of these communities (Love 2012).

Knowing the importance of consistent and deliberate study, as well as the importance of interacting with peers and maintaining a learning community, we have aimed to encourage students to form study groups from the beginning of the Human Anatomy and Physiology I course. In the past we have simply recommended that students form these groups but had not provided an incentive for them to consistently meet with peers. The first exam of the semester tends to be a learning experience for many students, with changes in study strategies implemented following receiving the results of the first exam. In an attempt to help students on

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their path to improve their preparation for exams, as well as improve their overall performance, we introduced incentives for participating in study groups with fellow classmates and utilized a tool to for accountability, which in this case was "selfies" of the study group. The goal was for students to increase the effectiveness of the time spent preparing for the course, while also forming positive study habits and establishing peer connections that can be carried with them throughout their undergraduate careers.

Procedure

At the first class meeting following Exam 1, we discussed with students a new process that would allow students to receive extra credit for assembling and attending weekly study groups. Students were briefly coached on how to effectively utilize study groups. They were advised to form groups with classmates with whom they could work well, rather than friends. They were encouraged to come to the group with specific questions to work through and to set goals for what should be accomplished at each meeting. Students were allowed to form their own groups. Help, such as the use of sign-up sheets to facilitate group formation, was provided if requested to match up students with groups. Students could have groups of between two to four students and were asked to take "study group selfies" at each meeting and send them to their instructor. The selfies needed to include a time/date stamp to indicate when the picture was taken, show all students in the group, and include evidence of studying (books, diagrams drawn on white boards, etc.) in an appropriate location.

Students would receive one point for each week that an appropriate selfie was sent, with up to ten total extra credit points available for the semester, with extra credit points being worth up to 2% of their final grade. While selfies were used in our study for tracking participation, it would be possible to use alternate forms of tracking such as sign in sheets in the library, group reports of what was accomplished, or physical check in with an instructor/administrator. We chose to use selfies, as this was something many of our students were already doing on a regular basis and allowed them to check in from anywhere they were studying. The key to this process was providing an incentive that provided bonus points to raise the overall course grade, as well as the ability to track participation in study groups throughout the semester. Many of the students were initially excited about this opportunity simply because of the opportunity to earn the ten extra points. Of 54 students enrolled in the course, 37 students participated in consistent study groups.

Study group participation was tracked throughout the remainder of the semester by collecting and tallying the study group selfies received. Some study group selfies were rejected if they did not meet the criteria. Exam score data were analyzed by comparing performance of students who participated in two or more study groups over the remaining ten weeks of the term, with the average student participating in one study group per week over ten weeks, versus those who participated in only one or none, in order to determine the impact of consistent study group participation. The "study group selfie" incentive was implemented following Exam 1 and Exam 1 was used as baseline data. At the end of the semester, overall course grades were also examined. The 37 students who participated in study groups were also given a qualitative survey to evaluate their perception of the how the study groups aided their performance in the class and the likelihood that they would continue with study groups in future courses. The Institutional Review Board of Elmhurst College approved this study, (IRB #FY19-005), and informed consent was obtained from all participants.

Conclusion

We determined that students who were most likely to take advantage of the study group incentives were also those who performed significantly lower on Exam 1 than those who did not take advantage of the incentives (Figure 1A). Many students who performed below their expectations on Exam 1 expressed interest in this incentive as a way to gain additional points in the course and raise their grades. Many students who performed well on Exam 1 likely did not take advantage of the study group incentives because they already had higher levels of performance and likely had already established good study habits. It is important to note that there was a small portion of students who already participated in study groups prior to Exam 1, with many of these students performing well on Exam 1 and throughout the course.

We then examined performance on subsequent exams following the implementation of the study group incentives and observed that in comparison to their baseline Exam 1 scores, students who participated in consistent study groups showed improved scores on all of their remaining exams. For the remaining exams (Exams 2, Exam 3, and the Final Exam (Figure 1A)) and overall course performance (Figure 1B) there was no statistical difference in performance for all students regardless of whether they participated in study groups or not.

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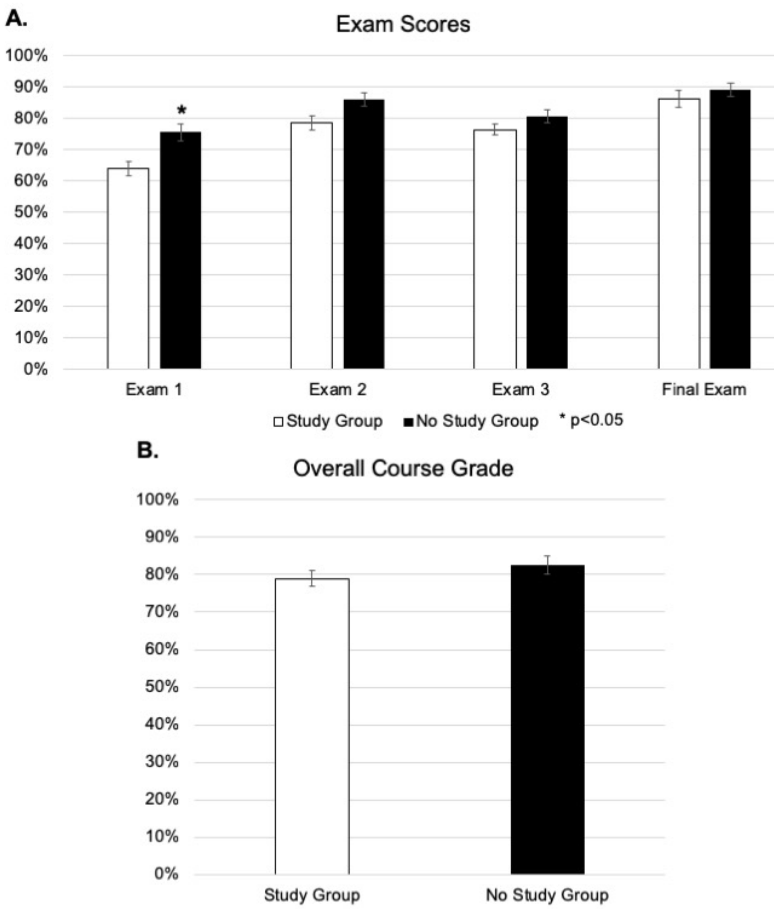

Figure 1. *Student Performance. A) Course Exam Performance. Students who participated in study groups performed significantly lower on exam 1 than those who did not participate on study groups. Following the formation and use of study groups, there was no significant difference in exam performance between the two groups. B) Overall Course Performance. At the end of the course there was no statistical difference in performance between the study group and no study group students.*

Student Response	Helped Keep on Track in Course	Helpful for Exam Preparation	Helped to Raise Grade
Agree	65.9%	74.4%	38.6%
Disagree	11.4%	4.7%	20.5%
Neutral	22.7%	20.9%	40.9%

Table 1. *Student Feedback Survey. Students were asked to respond to statements regarding the effectiveness of study group participation. Overall students found groups to be helpful in preparing for exams and keeping them on track, but did not see the benefit to their overall grade.*

Our data suggest that participating in consistent study groups with peers helped the initially weaker students improve their study habits and potentially contributed to their improved course performance. Based on feedback from students it appears this increase is due to several factors. Accountability and consistency were an overall theme of responses, with many students stating that meeting weekly with peers forced them to stay on top of the material because they did not want to be the one person holding the group back. Others stated that being able to talk through a process with a peer allowed them to realize what they did and did not know; giving them an opportunity to better focus their time spent studying.

In order to gain insight into student opinions of study group participation we collected survey data from those students who attended consistent study groups. Overall, students believed that the study groups helped to prepare them for the exams and to help them stay on track with the material for the course (Table 1). Interestingly, they did not associate the improvement of their grade with the attendance at study groups (Table 1).

While it is positive that students were able to see a correlation with the study group and preparation, the next step is educating students on the importance of utilizing a diverse range of study techniques that allow them to take ownership of their learning. Study groups not only reinforce the learning community and allow students to build peer connections, but also ensure that students study the same material multiple times in a variety of settings. The process of studying before, during, and after a study group increases the likelihood that students achieve a metacognitive awareness of what they know, and very importantly, what they do not know about course material. Helping students utilize metacognitive strategies to achieve self-regulated learning would be an important supplementary intervention in introductory Human Anatomy and Physiology courses (Sebesta and Bray Speth 2017).

An additional benefit of the specific chosen incentive employed here, the "study group selfie" draws on work that shows that selfies can be a mechanism for empowerment and connection to scientific spaces, particularly for traditionally marginalized groups (Liu et al. 2017). The study group selfie incentive is a fun, low resource opportunity for students to build both the learning community and their science identity.

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Literature Cited

Graham MJ, Frederick J, Byars-Winston A, Hunter A-B, Handelsman K. 2013. Increasing Persistence of College Students in STEM. *Science* 341 (6153):1455-1456.

Guenther MF, Johnson JL, Sawyer TP. 2019. The KEYSTONE Program: A Model for STEM Student Success and Retention at a Small Liberal Arts College. *J of Col Sci Teach* 48:8-13.

Gultice, A, Witham A, Kallmeyer R. 2015. Are your students ready for anatomy and physiology? Developing tools to identify students at risk for failure. *Adv in Phys Educ* 39:108-115.

Harris DE, Hannum L, Gupta S. 2004. Contributing Factors to Student Success in Anatomy and Physiology: Lower Outside Workload and Better Preparation. *The Amer Bio Teach* 66:168-175.

Hull K, Wilson S, Hopp R, Schaefer A, Jackson J. 2016. Determinants of Student Success in Anatomy and Physiology: Do Prerequisite Course Matter? A Task Force Review 2016. *HAPS Educ* 20:38-45.

Lewis KL, Stout JG, Pollock SJ, Finkelstein ND, Ito TA. 2016. Fitting in or opting out: A review of key social-psychological factors influencing a sense of belonging for women in physics. *Phys Rev Phys Educ Res* 12 (020110):1-10.

Light G, Micari M. 2013, Making Scientists: Six Principles for Effective Teaching. Harvard University Press. Cambridge, Massachusetts.

Love, Anne G. 2012. The Growth and Current State of Learning Communities in Higher Education. *New Direc for Teach and Learn*. 132:5-18.

Liu F, Ford D, Parnin C, and Dabbish L. 2017. Selfies as Social Movements: Influences on Participation and Perceived Impact on Stereotypes. *Proc of ACM Hum- Comp Interac* 72:1-21.

Nonis SA, Hudson GI. 2010. Performance of College Students: Impact of Study Time and Study Habits. *J of Educ for Bus* 85:229-238.

Plant EA, Ericsson KA, Hill L, Asberg K. 2005. Why study time does not predict grade point average across college students: Implications of deliberate practice for academic performance. *Contemp Educ Psyc* 30: 96-116.

Sandoval-Lucero E, Blasius E, Klingsmith L, Waite C. 2012. Student-Initiated Study Groups for STEM Classes in Community College Settings. *Higher Ed Stud* 2: 31-39.

Sebesta AJ and Brey Speth E. How Should I Study for the Exam? Sepf-Regulated Learning Strategies and Achievements in Introductory Biology. *CBE Life Sci Educ* 16:ar30: 1-12.

Strayhorn TL. 2019. College Students' Sense of Belonging: A Key to Educational Success for all Students. Taylor and Francis. New York, New York. 2-3, 73-86.

Sturges D and Maurer T. 2013. Allied Health Students' Perceptions of Class Difficulty: The Case of Undergraduate Human Anatomy and Physiology Classes. *The Int J of Allied Health Sci and Prac* 11,4.

Smith, B. L., MacGregor, J., Matthews, R. S., and Gabelnick, F. 2004. Learning Communities: Reforming Undergraduate Education. San Francisco: Jossey-Bass.

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Red State or Blue State Depends on the Ventilation Rate: A Respiratory Acid Base "Shock and Awe" Demonstration

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Abstract
This article describes a simple and inexpensive "shock and awe" classroom demonstration for understanding the importance of carbon dioxide (CO_2) in acid-base regulation. Before class, a solution was prepared by adding sodium bicarbonate and universal indicator solution to a sample of distilled water contained in a standard plastic water bottle. Upon arriving to class, the students observed the blue-violet solution and were told that the solution could be considered a surrogate for the arterial blood. At this point, a small piece of solid CO_2 (dry ice) was dropped into the bottle and a balloon, filled with confetti, was placed over the opening of the bottle. As expected, the solution rapidly turned bright pink/red as the solid CO_2 underwent sublimation and filled the balloon. At this point the balloon was "popped", making a loud noise and flying confetti about the room contributing to the "shock and awe" appeal. Furthermore, CO_2 was released simulating ventilation. To simulate hyperventilation, a piece of tubing connected to a hand bicycle pump was inserted into the bottle and air was pumped into the solution. As expected, the solution slowly changed from red to orange to yellow to green and finally approached blue as CO_2 was forced out of the solution. This straightforward and easy to perform demonstration provoked intense interest and provided a memorable learning experience by attracting and sustaining attention and increasing students' motivation to focus on the material. https://doi.org/10.21692/haps.2020.001

Key words: hyperventilation, hypoventilation, sublimation, carbon dioxide

Introduction

All the classroom is a stage…
and all the teachers and students
merely players
(apologies to William Shakespeare,
April 26, 1564 – April 23, 1616)

Teaching is not just about content; it is also about being a performer and entertainer. The content must do more than educate; it must also entertain, because teaching is a performance art and every presentation is a performance (Curran-Everett 2019). In the classroom, the teacher has the responsibility to communicate as well as engage and entertain (Savage et al. 2017). In this context, "shock and awe" classroom demonstrations engage and entertain by attracting and sustaining attention and increasing students' motivation to focus on class material, all of which aid in the learning process. Specifically, the spectacle and inherent drama of "shock and awe" classroom demonstrations offer emotionally engaging scientific theatre. Emotionally engaging scientific theatre stimulates significant student interest and exploits our primitive power of curiosity (Lujan and DiCarlo 2016; 2018; Lujan et al. 2019). To this end, we used a "shock and awe" classroom demonstration to create scientific theatre for understanding respiratory acidosis.

Background
Carbon dioxide (CO_2), in its normal range from a partial pressure of 38 to 42 mm Hg, plays important physiological roles. CO_2 regulates the pH of blood, stimulates breathing, and influences the affinity hemoglobin has for oxygen (O_2). Accordingly, variations in CO_2 levels are highly regulated and can cause disturbances if normal levels are not maintained. For example, by exhaling more CO_2 or less CO_2, the body can change the concentration of CO_2 in body fluid, and thereby regulate the pH of body fluid. During hypoventilation the rate of removal of CO_2 from the blood is decreased and shifts the hydration equation to the right. That is, when CO_2 dissolves in water, it forms a weak acid known as carbonic acid, H_2CO_3. H_2CO_3 can quickly dissociate into a hydrogen ion (H^+) and bicarbonate ion (HCO_3^-). The increase in the H^+ concentration causes the pH to decrease. Some of the H^+ produced when CO_2 acidifies the blood is buffered instantly by buffering systems found in bone, hemoglobin, and amino acids. The kidney subsequently produces "new HCO_3^-" that compensates for the increased [H^+] (Figure 1).

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In contrast, during hyperventilation the rate of removal of CO_2 from the blood is increased and shifts the hydration equation to the left. This leads to a decrease in the H^+ concentration and causes the pH to increase. Some H^+ is released from the bone, hemoglobin, and amino acids while the kidney eliminates HCO_3^- that compensates for the decreased $[H^+]$ (Figure 2).

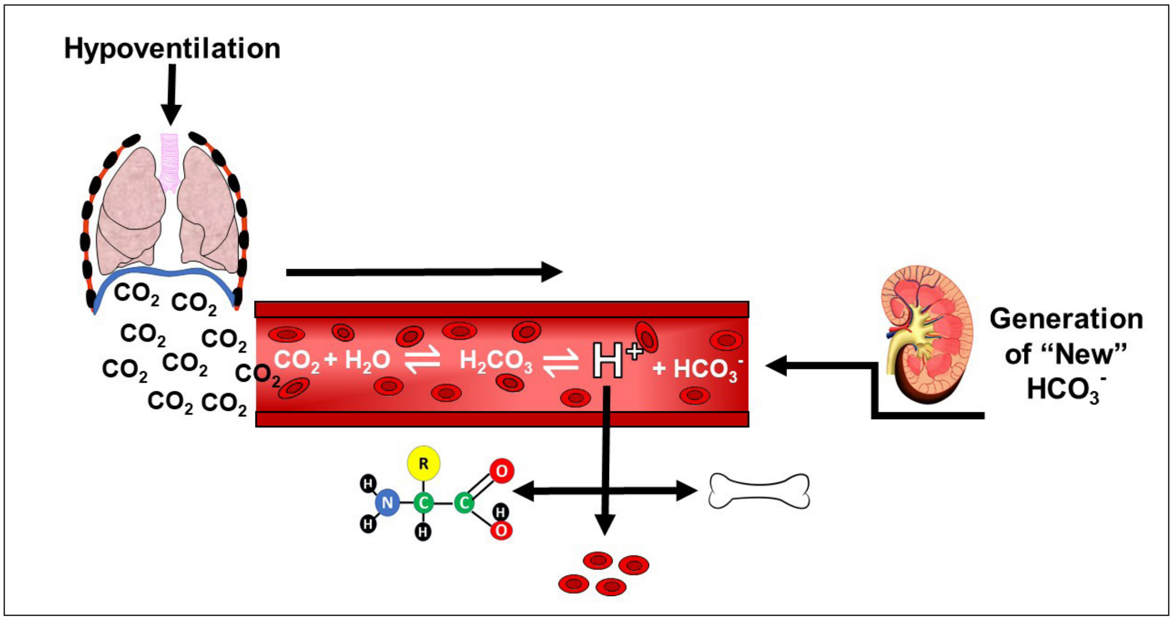

Figure 1. *Hypoventilation leads to an increased concentration of CO_2, which results in an increased H^+ concentration. The increased H^+ concentration results in decreased pH. Some of the H^+ produced when CO_2 acidifies the blood is buffered instantly by bone, hemoglobin, amino acids. The kidney produces "new HCO_3^-" which compensates for the increased $[H^+]$.*

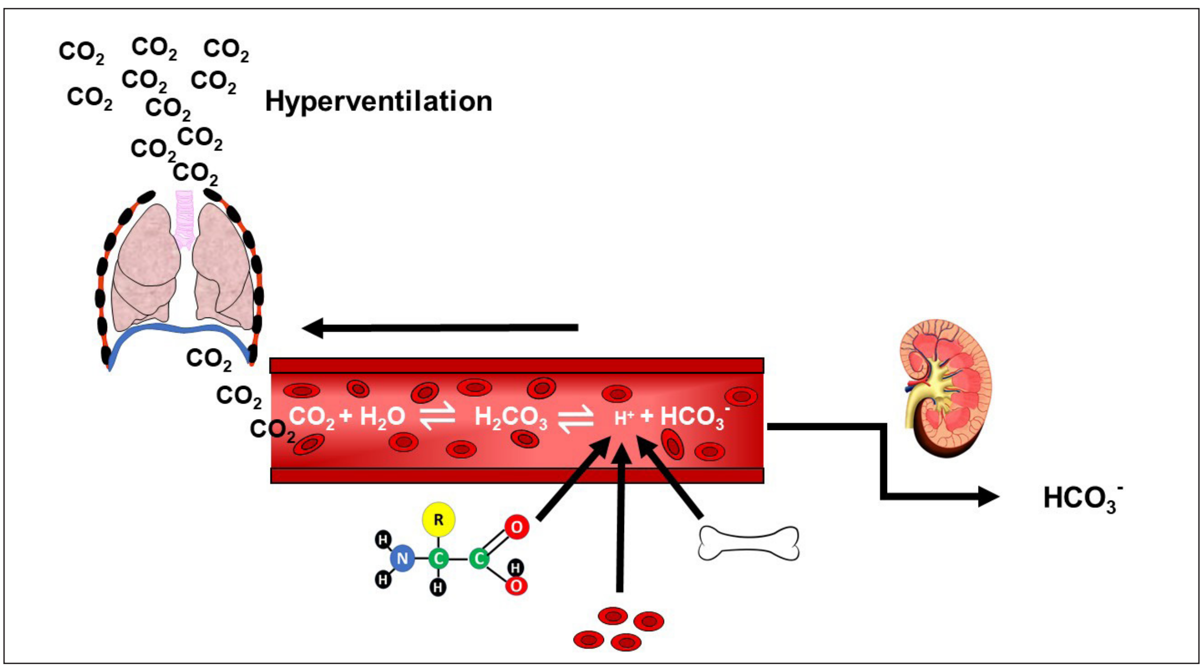

Figure 2. *Hyperventilation leads to a decreased concentration of CO_2, which results in a decreased H^+ concentration. The decreased H^+ concentration results in an increased pH. To compensate for the decreased H^+ concentration, some H^+ is released from the bone, hemoglobin, and amino acids while the kidney eliminates HCO_3^-.*

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Volatile acids

To help students understand the importance of CO_2 in acid-base regulation we begin with a discussion of volatile acids. Students are told that acid produced from CO_2 is called a volatile acid, because CO_2 is a gas that can be exhaled by the lungs. In fact, CO_2 is a colorless gas that comprises approximately 0.04% of Earth's atmosphere. In the human body, CO_2 is formed from the metabolism of carbohydrates, fats, and amino acids, in a process known as cellular respiration. The normal, resting CO_2 production is about 200 mL (8.9 mmol/per minute). This much CO_2 would yield 8.9 mmol of H^+ per minute. That is 12,800 mmol of H^+ per day. This rate of H^+ production, if it remained in body fluid as free H^+, would be fatal in minutes. However, a healthy respiratory system readily exhales this CO_2 as fast as it is produced so no net load of volatile acid accumulates in the body. All the other acids in the body (not produced from CO_2) are called non-volatile acids, non-carbonic acids, non-respiratory acids, metabolic acids, or fixed acids. Several metabolic processes produce fixed acids, and therefore increase the concentration of H^+ ($[H^+]$). Fixed acids are produced due to incomplete metabolism of carbohydrates (e.g. lactate), fats (e.g. ketones) and protein (e.g. sulphate, phosphate). Other metabolic processes produce bases and therefore consume H^+.

In this context, students, even advanced students, are often surprised to learn that nearly all the weight lost, for example with dieting, is exhaled by the lungs. As noted above, metabolism of fat produces carbon dioxide and water and we exhale the carbon dioxide and the water is lost as urine or sweat. In fact, metabolism of 4.5 kilograms (10 pounds) of fat results in 3.8 kilograms (8.4 pounds) being exhaled from the lungs and the remaining 0.7 kilograms (1.6 pounds) lost in the urine or sweat. Thus, nearly all the weight we lose is exhaled by the lungs (Meerman and Brown 2014).

The Demonstration

"No written word, no spoken plea can teach our youth what they should be; nor all the books on all the shelves --it's what the teachers are themselves."
Anonymous, quoted by John Wooden

To demonstrate the importance of CO_2 in acid-base regulation and model the scientific inquiry process, we created scientific theatre by presenting a "shock and awe" demonstration (Lujan and DiCarlo 2016; Lujan et al. 2019). Before class, we prepared a solution by adding 1 mL of universal indicator solution to a sample of distilled water contained in a standard plastic water bottle. The solution immediately displayed a yellow color, with a pH around 5.5. Tap water may be used; however, the color of the solution will be yellow or green/blue, depending on the acidity of the water. Next, 0.1 grams of sodium bicarbonate was added to the solution. The color of the solution turned blue-violet (Figure 3, Panel A). We also obtained a few small pieces of dry ice. Dry ice is the solid form of carbon dioxide.

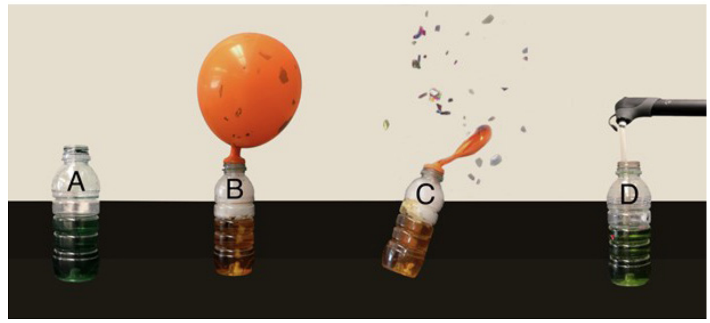

Figure 3. *The blue-violet solution (Panel A) was considered a surrogate for the arterial blood. A small piece of dry ice was dropped into the bottle and a 10-inch balloon, filled with confetti, was placed over the opening of the bottle (Panel B). The solution immediately turned bright pink/red and the balloon expanded as it filled with carbon dioxide (Panel B). To simulate respiratory compensation, the balloon was "popped" releasing the confetti and CO_2 (Figure 3, Panel C). Popping the balloon simulated ventilation. Finally, a catheter connected to a hand bicycle pump was inserted into the bottle and air was pumped into the solution. As expected, the solution slowly changed from red to green and eventually back to towards blue (Panel D).*

Upon arriving to class, the students observed the blue-violet solution and were told that the solution could be considered a surrogate for the arterial blood (Figure 3, Panel A). At this point, a small piece of solid CO_2 (dry ice) was dropped into the bottle and a balloon, filled with confetti (Lujan et al. 2019), was placed over the opening of the bottle (Figure 3, Panel B). As expected, the solution rapidly turned bright pink/red as the solid CO_2 underwent sublimation and filled the balloon. Sublimation is a chemical process where a solid converts into a gas without going through a liquid stage.

The solution turned pink/red because as the CO_2 dissolved in water, it formed a weak acid known as carbonic acid, H_2CO_3. H_2CO_3 dissociated into a hydrogen ion and bicarbonate ion. The addition of hydrogen reduced the pH [pH= negative log (activity H^+)]. Ion activity is also known as the effective ion concentration. Solutions with a high effective concentration of hydrogen ions have a low pH and solutions with a low effective concentration of hydrogen ions have a high pH. The balloon expansion (Figure 3, Panel B) represents CO_2 retention as occurs with hypoventilation (Figure 1).

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At this point the balloon was "popped", making a loud noise and flying confetti about the room contributing to the "shock and awe" appeal (Figure 3, Panel C) (Lujan and DiCarlo 2016; Lujan et al. 2019). Furthermore, CO_2 was released, simulating ventilation. To simulate hyperventilation, a piece of tubing connected to a hand bicycle pump was inserted into the bottle and air was pumped into the solution. As expected, the solution slowly changed from red to orange to yellow to green and finally approached blue as CO_2 was forced out of the solution (Figure 3, Panel D). Specifically, by pumping air with nearly no CO_2 into the bottle, the solution was mixed and exposed to the air. By creating a large surface area, the CO_2 diffused from the water into the lower- CO_2 air.

This simple, easy to perform demonstration provoked intense interest and provided a memorable learning experience because teaching is theatre. When we teach, we are acting. Our best "performance" occurs when we tap into our authentic emotions and connect with our students. When this happens, our students will be moved, and somehow changed intellectually and emotionally. Thus, the success of this demonstration may be attributable, in part, to a powerful emotional connection. All humans share basic emotions. When we experience emotion in our lives, we tend to remember the experience. In fact, the more emotional impact an experience has, the more intensely we remember its details and the more likely it will be stored in long-term memory (Lujan and DiCarlo 2016; 2018; Lujan et al. 2019). Accordingly, maybe we all should consider Amy Farrah Fowler's (fictional character in *The Big Bang Theory*, portrayed by Mayim Bialik) advice to Sheldon Lee Cooper (fictional character in *The Big Bang Theory*, portrayed by Jim Parsons) regarding improving his teaching (https://bigbangtrans.wordpress.com/series-4-episode-14-the-thespian-catalyst/):

Amy: Perhaps you should consider taking acting lessons.

Sheldon: Acting lessons. Interesting.
It might help if I could act as though I care about
my students and whether or not they learn.

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Literature Cited

Big Bang Theory Transcripts. https://bigbangtrans.wordpress.com/series-4-episode-14-the-thespian-catalyst/; [accessed 02/26/2020].

Curran-Everett, D. 2019. Every presentation is a performance. *Advances in Physiology Education*. 43(4):519-521.

Lujan, HL and DiCarlo, SE. 2016. Shock and awe pedagogy! *Advances in Physiology Education*. 40(4):467-468.

Lujan, HL and DiCarlo, SE. 2018. An acid-base "shock and awe" demonstration: The bad breath test. *Advances in Physiology Education*. 42(3):462-463.

Lujan, HL, Petersen, SA, LaFrance, NC, and DiCarlo, SE. 2019. In the pink and why so blue? A metabolic acidosis "shock-and-awe" demonstration. *Advances in Physiology Education*. 43(4):472-475.

Meerman, R and Brown, AJ. 2014. When somebody loses weight, where does the fat go? *BMJ : British Medical Journal*. 349:g7257.

Savage, BM, Lujan, HL, Thipparthi, RR, and DiCarlo, SE. 2017. Humor, laughter, learning, and health! A brief review. *Advances in Physiology Education*. 41(3):341-347.

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Testing in the Age of Active Learning: Test Question Templates Help to Align Activities and Assessments

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Abstract
Many undergraduate biology instructors incorporate active learning exercises into their lessons while continuing to assess students with traditional exams. To better align practice and exams, we present an approach to question-asking that emphasizes templates instead of specific questions. Students and instructors can use these Test Question Templates (TQTs) to generate many variations of questions for pre-exam practice and for the exams themselves. TQTs are specific enough to show students which material they should master, yet general enough to keep the exact exam questions a surprise and easy to change from term to term. TQTs generate biology problems analogous to other STEM disciplines' standard problems whose general format is known to students in advance. TQTs thus help instructors ask more exam questions at the higher-order cognitive levels of Bloom's taxonomy, while empowering students to prepare actively and creatively for such questions. https://doi.org/10.21692/haps.2020.006

Key words: study guides, problem sets, rubrics

Introduction
Six years ago, a comprehensive meta-analysis argued that active learning was unequivocally superior to traditional lecturing in terms of student learning gains in STEM courses (Freeman et al. 2014). There is growing acceptance of this conclusion among biology and STEM faculty, as reflected in faculty surveys (Patrick et al. 2016) and the expectation of many search committees that teaching demonstrations should include active-learning techniques (Smith et al. 2013). The actual implementation of active-learning techniques may lag behind perceived best practices (Stains et al. 2018), due in part to many instructors' belief that they must cover more content than active learning can accommodate (Miller and Metz 2014, Silverthorn 2020).

The momentum of the active learning movement does not address the fact that the term "active learning" encompasses many distinct teaching and learning strategies (Bonwell and Eason 1991). In fact, in the above-mentioned meta-analysis (Freeman et al. 2014), active learning was operationally defined to include almost any student activity other than reading, listening, or verbatim copying of notes. This diversity of active learning options is, overall, a good thing, since different instructional goals may be served best by different approaches (Tanner 2013). However, this diversity also raises the question of how such learning can best be demonstrated in summative assessments, especially traditional comprehensive fact-based tests, which are the primary determinant of students' final grades in most STEM courses (Goubeaud 2010, Momsen et al. 2010).

As STEM educators, we are interested in the extent to which these traditional assessments align with active learning as currently practiced in undergraduate courses (Pellegrino 2006, Reeves 2006). While we are unaware of comprehensive empirical data on this issue, we suspect that the active learning movement has not reformed testing to the same extent that it has reformed classroom lectures. Traditional tests may not be an ideal inventory of the fruits of active learning; for instance, if active-learning activities help students improve their higher-order cognition (HOC), such improvements may not be captured by typical undergraduate biology tests, which consist mostly of lower-order cognition (LOC) questions (Momsen et al. 2010). Improving summative assessments to better align with class assignments is a current major effort of national directives like the Next Generation Science Standards (NGSS Lead States 2013).

In considering the alignment between learning activities and subsequent tests, it is helpful to apply the principle of backwards design (Wiggins and McTighe 2005), which advises teachers to first define how they want their students to demonstrate mastery in summative assessments, and then to design learning activities that lead naturally to those assessments. Like most teachers, we want our students to be able to solve problems that go beyond the recognition and recitation of specific facts (Songer and Kali 2014). Backwards design would suggest that we identify appropriate problems on which students can be assessed, and then give the students numerous opportunities (e.g., classroom activities and homework assignments) to practice such problems prior to formal summative assessments. The practice should resemble the assessment, though not so closely that the practice gives away the exact nature of the assessment, which would then allow students to pre-prepare memorized answers without

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necessarily understanding them. Best practices indicate that it is useful to create opportunities for students to do the work of cognition both in performance and in their own independent practice (Pellegrino 2014). Specifically, the goal is to build novel, efficient assessments that reveal students' abilities to operate at HOC levels of engagement, as described in Bloom's taxonomy (Crowe et al. 2008, Anderson et al. 2001).

Introducing Test Question Templates

Here we describe an approach, which we call Test Question Templates (TQTs), for improving the alignment of learning activities and summative assessments. The word "template" is used to indicate that a TQT is not itself a question, but rather a question generator. A TQT can be used to generate a large number of distinct questions that conform to the template format (discussed below). The questions generated are suitable for tests as well as pre-test practice.

At its core, a TQT defines a relationship between an Input (the information given to the student) and an Output (what the student will do with the information given). For maximum clarity and transparency, a TQT should also include an Example (a specific case of an Input and the corresponding requested Output), a Key (a correct answer for the Example), and Other Answers (some imperfect responses along with notes on scoring them). Table 1 illustrates the structure of a TQT with an example in short-answer format; however, TQTs can just as easily be used to create multiple-choice questions, as shown in the footnote to Table 1.

TQT element	Example of element	Rationale
Input: Information to be given to the student.	"Given a table of the genetic code and a point mutation (reported in terms of the DNA coding strand OR the DNA template strand OR the mRNA)..."	This example indicates that students should know how to use a table of the genetic code, and should also be able to interconvert between the two DNA strands and mRNA.
Output: What the student will do with the information given.	"... determine the likelihood that the mutation will affect the function of the corresponding protein."	This example indicates that students should be able to convert codons to amino acids before and after the mutation, and thus see whether the amino acid changes (to another amino acid, or to a stop codon).
Example: A specific case of a possible question in the Input/Output format.	"Example: In an exon of the coding region of the coding strand for a particular gene, most people have the codon 5′-AGG-3′, but Jesse has codon 5′-CGG-3′. Is the corresponding protein likely to function differently in Jesse than in most other people? Show your work and explain your reasoning."*	An Example is vital for helping students see how a general Input-Output pair can be translated into a specific test question. The Example should ask for the same Output format (e.g., short answer or multiple-choice selection) as the test will.
Key: An answer to the Example that would earn full credit.	"Old DNA coding strand codon AGG => mRNA codon AGG => amino acid Arg. New DNA coding strand codon CGG => mRNA codon CGG => amino acid Arg. Since the old codon and the new codon both code for the same amino acid, Arg (arginine), no change in protein function is expected."	In addition to being a rudimentary rubric, students can use the Key for pre-test practice. If possible, put the Key in a separate file and encourage students to work through the Example before checking the Key.
Other Answers: examples of answers that would earn partial credit, with explanations of the scoring.	Example A: "The amino acid changes from Ser to Ala, so function might be impaired." [Shows understanding that a change in amino acid may alter function, but the conversions to amino acids were done wrong.] Example B: "Even though the amino acid is Arg in both cases, the change in DNA and RNA may cause problems." [The codons were translated correctly, but the answer does not convey that amino acid sequence dictates function.]	This optional TQT component can help students recognize and avoid common mistakes.

Table 1: *The structure and function of a Test Question Template*

**A multiple-choice version of this example might ask the same question and might provide choices like the following:*

- *(A) The amino acid changes from Ser to Ala, so the protein's function might be impaired.*
- *(B) The amino acid changes to a stop codon, so the protein is likely nonfunctional.*
- *(C) The change in DNA codon did not change the corresponding amino acid, so the protein's function should remain the same. [correct]*
- *(D) The change in DNA sequence might interfere with transcription.*

Additional TQTs for sophomore-level A&P courses -- with multiple-choice and short-answer examples -- are provided in the Appendix

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TQTs are given to students prior to tests, and thus constitute a kind of study guide. In general, study guides and other practice problems, whether delivered in class or not, are useful to students in flagging certain information as important (Lieu et al. 2017). However, for a typical practice question, once students have arrived at a good answer, it is unclear what additional steps (if any) they should take to prepare for a test. Should they commit this particular answer to memory? Should they think of variations on the original question, and, if so, which aspects of the original question should remain fixed, and which should be varied? Or should they just move on to the next question in order to get through as many questions as possible?

TQTs avoid such dilemmas by explicitly showing students the relationship between the practice questions and the test questions. If an instructor delineates key course content in the form of a TQT, the students can use the TQT to practice for the test, and the instructor can use the same TQT to generate actual test questions. Therefore, the alignment between the practice and the test is excellent, even though the exact details of the test questions are appropriately hidden from students and can easily be changed in subsequent iterations of the course. This close alignment should benefit all students, but especially at-risk groups such as first-generation college students, who might otherwise struggle to understand the instructor's expectations for tests (Wright et al. 2016). Furthermore, students who are language learners are likely to benefit from increasingly explicit modes of practice similar in format to the assessments used (Abedi, 2001).

Table 2 compares TQTs with two common study question formats: the "fact check" and the "mini-essay." To be clear, we find all three formats useful. However, as detailed in Table 2, we believe that TQTs have several advantages: they are arguably more specific than mini-essays, more general than fact checks, and more transparent and adaptable than either of these other formats.

	Fact Check	Mini-Essay	Test Question Template
Description	Students are asked to name one or more correct specific facts.	Students are asked to write a short correct narrative (describe a process, compare two things, etc.).	Given some specific information (textual or graphical), students answer a question about that information.
Typical cognitive level in Bloom's taxonomy	1 (Knowledge), 2 (Comprehension)	2 (Comprehension), 3 (Application), 4 (Analysis), 5 (Synthesis), 6 (Evaluation)	2 (Comprehension), 3 (Application), 4 (Analysis), 5 (Synthesis), 6 (Evaluation)
Nervous System example (for sophomore-level A&P)	What are the two general types of Na^+ channels found in the cell membranes of neurons, and in which parts of the neuron (dendrites, soma, axon) is each type located?	Explain how an electrical signal is passed from one neuron to another.	Given a graph of membrane potential versus time at the axon hillock of a neuron, identify the EPSPs, IPSPs, and action potentials.
Cardiovascular System example (for sophomore-level A&P)	List the cardiac structures specialized for electrical conduction, in the order that they are depolarized.	Why do the pacemaker cells of the heart depolarize spontaneously? Explain in terms of ion channels.	Given a specific alteration in the cardiac conduction pathway, explain which ECG time intervals would be most affected, and in which direction (increased or decreased).
Specificity: Is it usually clear which specific facts are needed to answer the stated question?	Yes	Maybe	Yes
Generality: Does the question usually highlight a theme of general importance?	Maybe	Yes	Yes
Transparency: Does the study question familiarize students with the format of test questions?	Maybe	Maybe	Yes
Adaptability: Does the question usually permit many variations appropriate for student practice and testing?	No	No	Yes

Table 2: *A comparison of Test Question Templates with conventional practice question formats*

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Tips for creating good TQTs

Those interested in the TQT format may wonder how they might create TQTs suitable for their own courses.

TQTs may be created for any topic in which many possible Inputs connect to many possible Outputs. Even a very straightforward template – for example, "Given the name of an organelle, summarize its function in a few words" may qualify as a TQT according to the definition outlined in Table 1, and may provide useful transparency to students. However, our main interest is in TQTs that encourage HOC, and that, therefore, are most appropriate for courses whose Learning Objectives (LOs) go beyond the mastery of factual details. If the LOs ask students only to *identify*, *list*, or *describe*, verbs commonly associated with the Knowledge and Comprehension levels of Bloom's taxonomy, there will not be many ways to ask about this information, and thus not enough variations to generate TQTs that require HOC. On the other hand, LOs that ask students to *analyze*, *critique*, *interpret*, or *predict*, verbs associated with the upper levels of Bloom's taxonomy, may be more readily translated into TQTs that require HOC.

An alternative to thinking in terms of LO verbs per se is the following; just about all HOC involves combining or reconciling two or more sources of information. Often, previously mastered background information (obtained from "source 1", often the textbook or teacher) is used to interpret a brand-new example (from "source 2", often the test itself). For the example in Table 1, background information on the genetic code (from source 1) is juxtaposed with the specifics of Jesse's DNA (from source 2). If we identify types of information that may be juxtaposed in numerous interesting ways, such that students need to think analytically, rather than simply memorizing the outcomes of all possible combinations, we may be able to craft a TQT that requires HOC.

An example of this "combinatorial" approach, showing how several aspects of the integumentary system might be combined in a TQT, is illustrated in Table 3. A conventional study question might ask students about relationships between UV light and other factors, with each relationship considered independently. The question can be made into a TQT by asking students to apply those known relationships to a new-to-them scenario about a particular patient. Only in the TQT version of the question do interesting interactions among the factors emerge, e.g., high melanin levels are beneficial in that they protect folate supplies and protect against skin cancer, but are undesirable in that they reduce endogenous vitamin D production and thus calcium absorption (HHMI Biointeractive 2015).

	Conventional study question	Test Question Template
Example	Indicate the impact (stimulatory, inhibitory, or neither) that UV light has on skin cancer incidence, melanin levels in the skin, rate of endogenous vitamin D production, rate of dietary calcium absorption, and plasma folate levels.	Given the results of an interview and physical exam of a patient -- including information on her natural melanin levels, sunlight exposure, and dietary (calcium, vitamin D, folate) habits and needs -- offer her sound medical or nutritional advice.
Comments on example	This is a straightforward five-part question: what effect does UV light have on each of five other variables?	This template covers the same variables as the conventional question, but is more interesting because there are more than five possible combinations to consider.
Number of possible variations of question	Few	Many
"Memorizability" of answers to all possible questions	High	Low
Importance of reasoning ability in answering the question	Low	High

Table 3: *Test Question Templates may motivate students to pursue true understanding rather than pure memorization*

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While the TQT example in Table 3 is a clinical one, some clinical issues cannot be readily translated into TQTs. For example, if a sophomore-level physiology course covers only a couple of neuromuscular disorders, it would not make much sense to have a TQT of the form of, "given some symptoms, diagnose a patient's neuromuscular disorder." And if a course mentions numerous disorders, but only does so in passing, students may not have the knowledge needed to think analytically about the disorders. Thus, while clinical applications are often interesting to students and good for stimulating critical thinking, instructors who create clinical TQTs should take care not to presume background knowledge or analytical skills that their students do not yet have.

Whether clinically focused or not, most instructors probably have existing practice questions that can be converted into TQTs. The key is to recognize questions that represent specific examples of a general pattern. For example, imagine that your study guide asks students to calculate cardiac output from an end-systolic volume of 60 mL, an end-diastolic volume of 140 mL, and a heart rate of 50 beats per minute. Presumably you would like your students to be able to solve any similar problem involving the cardiac output equation. This expectation can be made more transparent by giving students a TQT such as the following: "Given values for three of the following four variables -- end-systolic volume, end-diastolic volume, heart rate, and cardiac output -- solve for the fourth variable." The original study-guide problem could then serve as an example of a question generated by this TQT.

An additional consideration is that, ideally, a TQT would reflect the type of active learning activity that was originally used to teach the content. For example, if students initially learned about histology by examining microscope slides, an ideal TQT might also involve the analysis of new (but related) microscope slides. However, if this is not feasible, the TQT could instead involve electronic images and/or text descriptions.

These last two examples -- the cardiac output calculation and the histology images -- illustrate the fact that simple mathematical analyses and figures are often an excellent basis for TQTs. For equations and graphs, the exact numbers and curve shapes can be varied endlessly, allowing students to get unlimited practice on important mathematical relationships. This also furthers the important goal of integrating more quantitative skill development into biology (Brewer and Smith 2011). Likewise, for qualitative figures, there are numerous versions that students have not seen before, yet should be able to analyze after previous experience with similar figures.

A variation on the use of qualitative figures is the following, which we have borrowed from the "Public Exam" system (Wiggins 2019). Give students a specific figure to study in advance, often a complex but important one (e.g., of the blood clotting cascade), along with examples of questions that could be asked about the figure. Assure students that they will have a copy of the figure during the test. The clear message to students is that this figure should be understood in depth, but does not need to be memorized. The advantage to instructors, in this case, is that they do not need to search for novel figures; they can simply use existing figures that are already central to their lessons.

Supporting students' use of TQTs

Many undergraduate students think of biology as an endless series of specific, unique questions, each with its own specific, unique answer. Since TQTs, by contrast, involve more general patterns of questions, students deserve explicit guidance on this alternative approach. If TQTs will be used to generate test questions, they should be introduced and explained during formative assessments. Cooperative learning formats such as think-pair-share (Mazur 1996), and jigsaws such as those used in Theobald et al. 2017, can be especially beneficial because students can help each other with the format of the questions, as well as the relevant content. Students who encounter TQTs early and often will be well-equipped to handle TQT-generated questions on actual tests.

Even if the TQT format is explained carefully, with examples, many students may simply study the instructor-provided examples without creating their own additional examples. However, such students would miss a primary advantage of TQTs, namely, the opportunity to create their own additional practice questions. For this reason, students should be explicitly assigned the task of creating novel TQT-based questions. This assignment can benefit from a group-learning context; students can check each other's creations, try to solve the ones that seem most plausible as test questions, and grade each other's answers. Instructors should monitor these efforts, if possible, to ensure that no group is straying too far from the original intent of each TQT.

Preliminary student feedback on TQTs

In order to examine student views on topics covered in this paper, we administered a brief questionnaire to students who had taken a course that used TQTs. (The Everett Community College IRB affirmed that this survey was exempt from formal IRB review.) Of the 76 students enrolled in two courses, 35 opted to read this manuscript and respond to the questionnaire. The questionnaire consisted of three open-ended questions:

1. In your view, what are the main CLAIMS (central assertions or arguments) being made by this paper? Please list at least two claims.
2. To what extent do you agree or disagree with the claims listed in the previous response? Please be assured that it is OK to disagree! Explain why you agree and/or disagree with each claim.
3. Aside from the claims covered by the previous two questions, what other comments (if any) do you have about this paper?

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We coded students' responses to the first question as high, moderate, or low with regard to their level of comprehension of the manuscript. We excluded from the full analysis any student whose responses reflected a low level of comprehension, in that the response did not identify a claim of the paper or lacked sufficient detail to assess comprehension. We then coded the remaining 30 student responses with the qualitative data analysis software program, MAXQDA, applying a grounded theory approach to text analysis (Strauss and Corbin 1998), which is an iterative inductive process of coding concepts that arise from the data and linking these concepts into themes. Our analysis yielded four themes which consistently arose across student responses.

The most general of these four themes was the idea that active learning in general (not necessarily TQTs in particular) is helpful for student learning. For example, one student wrote, "We need more active learning in classrooms so students better understand material and not just memorize facts."

Two additional themes centered more specifically on TQTs. These themes were, first, that TQTs especially help students learn new material more deeply, and, second, that TQTs are useful for reviewing previously covered material in preparation for exams. The first theme was exemplified by student comments such as the following: "Incorporating TQTs … will better promote active learning in students by not just memorizing facts given, but to further understand the context and apply it to deeper thinking problems." The second theme, focusing more on exam preparation, was echoed in comments such as, "As a student, when I have sample question [sic] that include the same material that will be on the exam I study more and make sure that I actually know the material even if the sentence gets rearranged or numbers get changed. It makes it easy for students to know exactly what to study and focus more on, instead of studying the whole book. I think its [sic] really unrealistic when a teacher makes you study absolutely everything they covered in class."

All of the students agreed in part or in whole with the claims they identified in the manuscript. The few who agreed only in part largely expressed an additional theme, namely, that students may struggle with how to use TQTs when first introduced to them. One representative comment was the following: "TQTs can be good as long as students understand how to solve them and understand them. And so I believe for TQTs to work, it would need to be integrated in school learning…. It can be very frustrating and confusing when given something like a TQTs question on the exam and you never came across that type of question before." This insight, that even an otherwise helpful format such as a TQT can be confusing in the absence of repeated exposure, underscores our suggestion above that students be given explicit, extensive training in TQTs well before the first exam.

Other approaches

As noted earlier, promoting HOC, both during personal practice and during summative assessments, is considered an educational best practice (Pellegrino 2014). The literature in developing assessments that promote higher-order thinking and learning in the K-12 system is rich (e.g., Darling-Hammond and Adamson 2014). TQTs thus represent one of many possible ways of aligning practice and assessment of HOC. Analogous approaches in fields that habitually use algorithmic or equation-based calculations may routinely do TQT-like work without explicitly stating it. Specifically, physics and engineering exams commonly include questions on the application of formulae to physical problems. The TQT framework may help to make the design of these assessments more transparent for students. Learning progressions are an effective way to formalize assessment-ready pieces of curriculum by investigating how students proceed towards mastery (Scott et al. 2019). Development of learning progressions is laborious but highly useful and will achieve goals overlapping with those of TQTs. Other formulations of exam-presentation tools for students, such as the "Public Exam" system (Wiggins 2019), may also be useful to educators looking to move beyond traditional exam styles.

Summary

Biology instructors want to help their students go beyond isolated facts to master fundamental, general patterns and skills. In-depth active-learning activities are great for inspiring deep learning, but students may not fully engage in these activities if they do not see strong connections between these learning activities and subsequent high-stakes exams. TQTs represent an approach, newly formulated, yet similar to other existing frameworks, to bridge the gap between practice questions and exam questions. By improving the transparency of instructors' exam-writing, TQTs help instructors and students avoid the cat-and-mouse game of "What's going to be on the exam?" and instead provide students with rich opportunities for creative, analytical practice with the course's most important material.

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Literature cited

Abedi J and Lord C. 2001. The language factor in mathematics tests. *Appl Meas Educ* 14(3): 219-234.

Anderson LW, Krathwohl DR, Airasian PW, Cruikshank KA, Mayer RE, Pintrich, PR, ... & Wittrock MC. 2001. A taxonomy for learning, teaching, and assessing: A revision of Bloom's taxonomy of educational objectives, abridged edition. White Plains, NY: Longman.

Bonwell CC and Eison JA. 1991. Active learning: creating excitement in the classroom. ASHE-ERIC Higher Education Reports. Washington, DC: The George Washington University, School of Education and Human Development.

Brewer CA, Smith D. 2011. Vision and change in undergraduate biology education: a call to action. Washington, DC: American Association for the Advancement of Science.

Crowe A, Dirks C, Wenderoth MP. 2008; Biology in bloom: implementing Bloom's taxonomy to enhance student learning in biology. *CBE Life Sci Educ* 7(4):368-381.

Darling-Hammond L, Adamson F. 2014. Beyond the bubble test: How performance assessments support 21st century learning. San Francisco, CA: John Wiley & Sons.

Freeman S, Eddy SL, McDonough M, Smith MK, Okoroafor N, Jordt H, Wenderoth MP. 2014. Active learning increases student performance in science, engineering, and mathematics. *Proc Natl Acad Sci U S A* 111(23):8410-8415.

Goubeaud K. 2010. How is science learning assessed at the postsecondary level? Assessment and grading practices in college biology, chemistry and physics. *J Sci Educ Technol* 19(3): 237-245.

HHMI Biointeractive. 2015. The biology of skin color. https://www.biointeractive.org/classroom-resources/biology-skin-color.

Lieu R, Wong A, Asefirad A, Shaffer JF. 2017. Improving exam performance in introductory biology through the use of preclass reading guides. *CBE Life Sci Educ* 16(3): ar46.

Mazur E. 1996. Peer instruction: A user's manual. Boston: Pearson.

Miller CJ, Metz MJ. 2014. A comparison of professional-level faculty and student perceptions of active learning: its current use, effectiveness, and barriers. *Adv Physiol Educ* 38(3): 246-252.

Momsen JL, Long TM, Wyse SA, Ebert-May D. 2010. Just the facts? Introductory undergraduate biology courses focus on low-level cognitive skills. *CBE Life Sci Educ* 9(4):435-440.

NGSS Lead States. 2013. Next generation science standards: For states, by states. Washington, DC: National Academies Press.

Patrick LE, Howell LA, Wischusen W. 2016. Perceptions of active learning between faculty and undergraduates: Differing views among departments. *J STEM Educ Innov Res* 17(3): 55-63.

Pellegrino JW. 2006. Rethinking and redesigning curriculum, instruction and assessment: What contemporary research and theory suggests. Chicago: National Center on Education and the Economy.

Pellegrino JW. 2014. A Learning sciences perspective on the design and use of assessment in education. In: Sawyer RK, editor. The Cambridge handbook of the learning sciences. Cambridge, UK: Cambridge University Press.

Reeves TC. 2006. How do you know they are learning? The importance of alignment in higher education. *Int J Learn Technol 2*(4): 294-309.

Scott EE, Wenderoth MP, Doherty JH. 2019. Learning Progressions: An Empirically Grounded, Learner-Centered Framework to Guide Biology Instruction. *CBE Life Sci Educ* 18(4): es5.

Silverthorn DU. 2020. When active learning fails … and what to do about it. In: Mintzes JJ, Walter EM, editors. Active learning in college science: The case for evidence-based practice. Berlin: Springer, p. 985-1001.

Songer NB, Kali Y. 2014. Science education and the learning sciences as coevolving species. In: Sawyer RK, editor. The Cambridge handbook of the learning sciences. Cambridge, UK: Cambridge University Press.

Smith MK, Wenderoth MP, Tyler M. 2013. The teaching demonstration: what faculty expect and how to prepare for this aspect of the job interview. *CBE Life Sci Educ* 12(1): 12-18.

Stains M et al. 2018. Anatomy of STEM teaching in North American universities. *Science* 359: 1468-1470.

Strauss AL and Corbin J. 1998. Basics of qualitative research: Techniques and procedures for developing grounded theory. Thousand Oaks, CA: SAGE Publications, Inc.

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Tanner KD. 2013. Structure Matters: Twenty-One Teaching Strategies to Promote Student Engagement and Cultivate Classroom Equity. *CBE Life Sci Educ* 12(3): 322-331.

Theobald EJ, Eddy SL, Grunspan DZ, Wiggins BL, Crowe AJ. 2017. Student perception of group dynamics predicts individual performance: Comfort and equity matter. *PLoS ONE* 12(7): e0181336.

Wiggins B. 2019. The Public Exam System: Simple Steps to More Effective Tests. https://www.coursehero.com/faculty-club/classroom-tips/benjamin-wiggins/.

Wiggins G, McTighe J. 2005. Understanding by Design [2nd edition]. Alexandria, VA: Association for Supervision and Curriculum Development (ASCD).

Wright CD, Eddy SL, Wenderoth MP, Abshire E, Blankenbiller M, Brownell SE. 2016. Cognitive Difficulty and Format of Exams Predicts Gender and Socioeconomic Gaps in Exam Performance of Students in Introductory Biology Courses. *CBE Life Sci Educ* 15: 1-16.

Appendix Hyperlink

Follow the link below to view and download the pdf appendix to this article.

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The Benefits of Near-Peer Teaching Assistants in the Anatomy and Physiology Lab: An Instructor and a Student's Perspective on a Novel Experience

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Abstract

Near-peer teaching, in which students one or more years removed from a student within the same academic program, is utilized broadly in medical school curricula and increasingly in undergraduate anatomy and physiology courses. While the literature on near-peer teaching suggests that the practice is overwhelmingly positive, it is primarily from anatomy courses in a medical school setting. Therefore, instructors who implement near-peer programs at the undergraduate level should share their experiences and evaluate these programs on an ongoing basis. The purpose of this paper is to share a personal experience with utilizing undergraduates as teaching assistants in the anatomy and physiology laboratory setting. A detailed description of the near-peer experience is first provided, followed by the observed benefits for everyone involved from both the instructor and a near-peer's perspective. Finally, recommendations are made for implementing a near-peer program with future directions for research into evaluating outcomes of a near-peer program. http://doi.org/10.21692/haps.2020.003

Key words: near-peer teaching, near-peer learning, faculty-to-student ratio, laboratory, mentoring

Introduction

Anatomy and Physiology is a traditionally challenging course, particularly for first year students. Reasons for difficulty in this course have been investigated (Anderton e*t al.* 2016; Gultice et al. 2015; Rompolski et al. 2016; Russell et al. 2016; Sturges et al. 2016). Students often overestimate their knowledge and preparedness and only realize they are not meeting their learning outcomes after a major assessment (Eagleton 2015; Sturges 2016). In response, increasing attention is being devoted to the importance of regular retrieval practice and low-stakes formative assessment with timely, regular feedback to close the gaps between student perceptions of their understanding and actual competency (Dobson 2013).

Due to the nature of the laboratory setting, laboratory sessions in Anatomy and Physiology present valuable opportunities for active learning and application of concepts being studied and presented in the classroom. While debate continues as to what laboratory experiences are the most valuable in meeting learning outcomes in Anatomy and Physiology, and how to structure and assess those outcomes, there is little debate that a greater faculty-to-student ratio increases the chance that students will receive valuable guidance and feedback. To meet the demands of increasing enrollment and lower faculty-to-student ratios in higher education, many instructors employ and rely on near-peer teachers to assist in their courses (Duran et al. 2012; Hopp et al. 2019).

Near-peer teaching is a type of peer teaching in which students who are one or more years senior in the same program as the more junior students, and have previously completed the same coursework or activities, teach some portion of the course (Bulte 2007). Near-peer teaching may occur in a variety of formats. Near-peers can act as assistants in the classroom for active learning exercises, function as laboratory instructors or assistants, or hold open lab hours (Hopp *et al*. 2019). Near-peer teaching is widely implemented in medical curricula, with evidence demonstrating that near-peers make effective facilitators, information resources, and role models for junior students (Bulte 2007; Reyes-Hernandez et al. 2015).

A recent systematic review of the literature on peer teaching in undergraduate medical education found that knowledge and skills outcomes do not differ between students taught by faculty and students taught by near-peers, and suggested that peer teaching continue to be supported for its power to increase the knowledge and teaching skills of the peer teachers (Rees et al. 2016). Traditionally, students engaged in graduate studies, usually labeled teaching assistants (TAs), assisted instructors in undergraduate courses, whether to fulfill an obligation for an assistantship, or to gain experience for a desired teaching career. However, TAs may not necessarily have gone through the same program, or even gone to the same school as the students they are assisting.

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Near-peer teachers are usually chosen for having been successful in the same course that their junior peers are taking and are highly motivated and enthusiastic about the subject matter. Both graduate assistants and undergraduate assistants are typically trained by the instructor of the course, or through some formal training program, and are carefully monitored, via direct observation by the instructor or student and near-peer feedback (Evans 2009; Hopp *et al*. 2019). A recent exploratory study by Hopp and colleagues into the use of TAs in Anatomy and Physiology found that nearly all participants surveyed reported utilizing TAs in some capacity in their Anatomy and Physiology curriculum. Of those institutions that did not utilize TAs, concerns such as lack of funding, small class sizes, and concerns about TA quality were the prevailing reasons. Of those that did utilize TAs, both undergraduate and graduate TAs were utilized, with graduate students dominating in the four-year public nonprofit universities and undergraduate being the most frequently used in four-year private institutions (Hopp *et al*. 2019).

This paper describes a novel near-peer laboratory teaching program that I, the instructor, piloted at my former institution. The paper is written from my perspective, with the exception of one section in which one of the near-peers, the second author, shares her experience. Prior to the development of this program, only faculty members taught the laboratory courses, and one graduate teaching assistant worked with the instructors in some of the labs as part of their assistantship requirements. Due to increasing admissions in the nursing and health sciences majors, the Anatomy and Physiology laboratory enrollments were increased to 40 students per lab, with a graduate teaching assistant and faculty member assigned to each lab. To further improve the ratio, I utilized both the independent study and senior research project electives in the Health Sciences major to personally mentor two students per quarter (winter and spring quarters of 2019) as near-peer teachers.

Here, I provide a detailed description of the activities that the near-peers were required to engage in for satisfactory completion, expectations I set for the near-peers, and myself, and the benefits of this program for everyone involved. I make recommendations for the successful implementation of a near-peer teaching program in the Anatomy and Physiology lab based on our personal experience and work done by other Anatomy and Physiology teachers. Finally, a personal perspective from the second author, who was one of the near-peers and was actively involved in the creation of the near-peer experience, is presented.

The Creation of the Near-Peer Experience

As near-peer teaching and mentoring had never been done in the department, I identified a few students who I felt would benefit greatly from the experience and would serve as positive role models for the students in the course. The invited students were successful in Anatomy and Physiology (B or better in the course series), expressed enthusiasm for the subject matter, were frequently observed assisting their fellow classmates in the understanding of concepts, had regularly reached out to me to review exams or confirm their understanding of course material, and expressed a desire to find ways to continually reinforce their Anatomy and Physiology knowledge prior to entering graduate school. Similar selection criteria have previously been applied to the identification and selection of near-peer teachers (Evans 2009). If the students were interested, they registered for either a two or three credit independent study option, or a three-credit senior project. The students that were seniors were expected, as part of their overall grading, to publicly disseminate their experience in some way. I was assigned to teach two labs each quarter; so one student was assigned to each lab with me, along with the graduate teaching assistant. The invitation sent to the potential near-peer students is provided in Appendix 1.

Time Commitment and Schedule for the Near-Peers and Instructors

The average weekly time commitment for all of the near-peers' activities was approximately ten hours. I met with the near-peers for one to two hours once per week to prepare for the upcoming lab. The near-peers were required to attend each Anatomy and Physiology lab, arrive a half hour early, and stay an additional half hour for clean-up and debriefing. This totaled three hours. The near-peers were also asked to critically appraise assigned online/virtual laboratory activities provided by the textbook publisher being used in the Anatomy and Physiology curriculum. Finally, the near-peers were required to submit three reflective portfolios of their experience, utilizing Kolb's cycle of learning (Kolb 1984). These activities totaled approximately nine hours of activities per week. I checked in weekly with the near-peers to monitor if the activities were taking up more time than expected and adjusted accordingly as to not over-burden the near-peers or distract from their other coursework. The senior students completed an additional activity, one in the form of a *HAPS Educator* publication, and the other a presentation about near-peer teaching at the university's day of undergraduate excellence.

Weekly Meetings - A Critical Component to the Success of Near-Peer Mentorship

In order to ensure that the near-peers and the graduate teaching assistant had prepared well for the lab experience and, just as importantly, felt confident in their ability to assist junior students, I met with the near-peers weekly to run through every step of the laboratory experience and monitor their progress. In my role as the director of the Anatomy and Physiology curriculum, I revised all of the laboratory handouts and exercises that year to be tied to HAPS Learning Outcomes, with numerous guided inquiry questions tied to their laboratory exercises.

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The near-peers were not provided with an instructor's key to the labs. They were expected to come to the weekly meeting with the pre-laboratory exercises completed, and then run through the lab as if they were a student taking the lab. Since the curriculum had only been revised in the current year, the near-peer students had not yet experienced these laboratories in the new format, eliminating previous exposure from influencing their performance.

The two near-peers met at the same time, and worked together to complete all the laboratory activities independently. I was present at all times to confirm findings and correct answers depending on the activities in question. I strongly emphasized to the near-peers that they should be honest if they did not understand a concept, or didn't feel confident in their understanding, so that I could support them and overcome these difficulties. It was very important that the students felt comfortable and safe expressing difficulty and embracing the vulnerability of having to overcome a barrier to learning. We consistently dialogued throughout the lab meeting about what it felt like to be learning the material for the first time, and how powerful and important modeling the beginner's mindset to their junior peers could be in helping them overcome their anxiety.

The near-peers were told that if they did not know the answer to a student's question during lab, that they should never improvise an answer and instead, ask me to come to the group and offer assistance. The laboratory students were also made aware that the near-peers were not subject matter experts, and were asked to defer to me when they were unsure. In this manner, the near-peers felt less anxiety about not having every answer, and the students could feel comfortable that they would not be misled or receive inaccurate information from the near-peers.

Once the near-peers completed all the laboratory activities and were sure that their answers to the laboratory prep handouts, I asked them to take the post-laboratory quiz, so that they knew what the students would be assessed on after lab. If the near-peers scored anything incorrectly, we reviewed that material again. The near-peers were strongly encouraged to tell me if they did not understand the phrasing of a question, felt that more than one answer could be accepted, or, felt that the laboratory activities and learning outcomes were not reflected in the quiz.

Weekly Lab Experiences

The near-peer laboratory teaching experiences occurred during the semesters in which Anatomy and Physiology II and III occurred. This university was on a quarter system, rather than semester system, and the Anatomy and Physiology series was split into three, ten-week sessions. This institution had a human anatomy lab with over 12 cadavers dissected by the Doctor of Physical Therapy students, as well as lab equipment for physiology experimentation. Laboratory experiences in Anatomy and Physiology II included study of the gross anatomy of the brain, spinal cord, peripheral nerves, digestive and endocrine systems, and physiology experimentation of the cranial nerves, spinal reflexes, blood glucose regulation, and the dive response. In Anatomy and Physiology III, students studied the gross anatomy of the heart and circulatory system, the respiratory system, the reproductive and urinary systems, and engaged in physiology laboratories that examined EKGs, heart sounds, ventilation/lung volumes and hormonal control of the ovarian cycle.

Approximately one week prior to the laboratory experience, I posted pre-lab preparatory activities and strategies for success in the learning management system for all students taking Anatomy and Physiology labs. On the first day of the labs, I introduced the lab students to the near-peer and explained their role. As previously described, I made it clear to the lab students that the near-peer students were instructed to always ask me if they were not sure of an answer and were not expected to be subject matter experts. The lab students were debriefed on what I expected of the near-peers in terms of student engagement. The near-peers were expected to:

1. Continuously engage with students by asking them questions to investigate understanding and practice recall.
2. Learn the names of students by the second lab.
3. Give all lab students equal attention, and particularly ask questions of students who seem to be idle.
4. Ask the instructor for help if they did not know how to help a lab student.
5. Be enthusiastic and relatable.

I explained the rationale for the near-peer experience to the Anatomy and Physiology lab students to encourage enthusiasm for the experience. As the labs are largely self-directed by the lab students, we circulated during the labs to provide assistance as needed and make sure that they were accomplishing all of their tasks. As each lab was filled with activities, I developed a number of supplemental activities to challenge lab students who claimed they were done earlier than expected, or to provide an extra level of challenge to

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those who wanted it. In the latter half of the quarter, I asked the near-peer students to try to develop these activities instead. These often revealed to the Anatomy and Physiology students that they did not, indeed, understand or retain the information and needed to spend more time engaging with the material prior to the laboratory quiz.

I instructed the near-peers not to immediately answer lab student's questions, as this might lead to reliance on the near-peers. Instead, we discussed strategies to guide the lab students through a critical thinking process to come to the correct answers or understanding of a concept. Additionally, we discussed how to do this in a supportive, inspiring manner to avoid the students feeling embarrassed or discouraged when answering questions.

Critique of Online Laboratories

As enrollments were projected to grow, the other Anatomy and Physiology instructors and I were considering the possibility of adding online laboratory experiences, or even developing an online Anatomy and Physiology course series. Recognizing that someone with expertise in a subject matter may have a limited ability to assess student perception and value of an online laboratory experience, I asked each near-peer to do a one to two-page write up about their experience completing three or four online labs that came with the digital platform being used at the time. To gain better insight into the potential mismatch between what an experienced instructor and a student who just completed Anatomy and Physiology would find valuable, I chose and completed all the labs on my own, prior to assigning them to the near peers for feedback. The labs that were ultimately chosen were ones that the near-peers felt were:

1. Straightforward to do.
2. Fun and engaging throughout.
3. Helpful in understanding a difficult concept.
4. Fit well into the curriculum.

If any of those criteria were not met by the near-peer, they were not chosen for future utilization, even if I had initially thought they would be useful online labs to assign.

Reflective Portfolios

To promote skills of self-reflection and self-monitoring, the near-peer students were required to submit three reflections throughout the quarter, once every three weeks. I believed that this would be an important part of the personal and professional development of the near-peers and would provide me with insight on how the peers were progressing through the experience (McLeod 2017).

To familiarize students with experiential learning, I sent students literature on the topic, as well as sample portfolios from my work in the Anatomical Society's Anatomy Training Program, in which trainees are required to keep monthly reflective portfolios (Fraher & Evans 2009). Experiential learning fit this scenario best as the near peers were actively engaged in activities that were concrete experiences that provided an opportunity for observation of the behavior of themselves and others, analysis of that experience, and hypothesis generation for future experiences. Also, as the near-peer experience is intended to help students think about how learning happens, both in themselves and their junior students, Kolb's theory that "learning is the process whereby knowledge is created through the transformation of experience" was very suitable. An example of Kolb's learning cycle theory applied to the near-peer experience is shown in Figure 1.

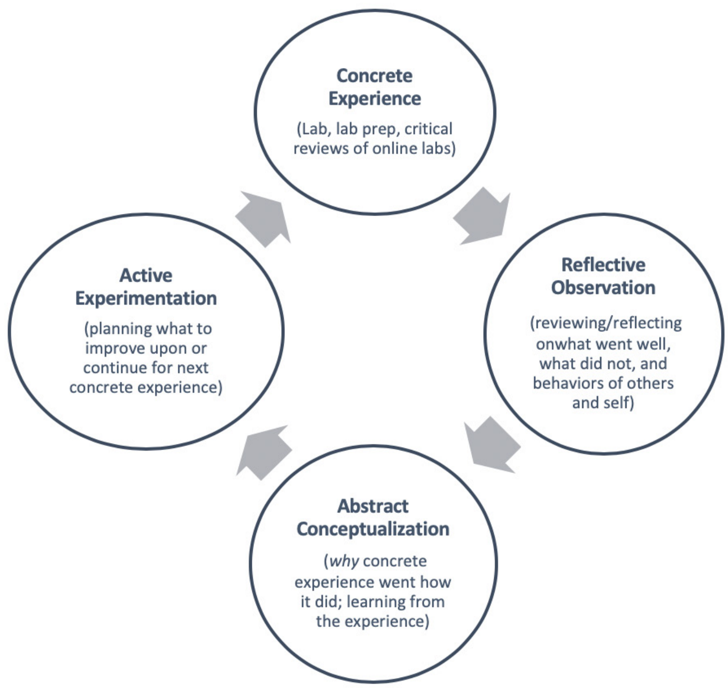

Figure 1. *Kolb's experiential learning cycle as a near-peer in the Anatomy and Physiology laboratory.*

Within 48 hours of the submission of a reflective portfolio, I provided the near peer with detailed feedback on their portfolios. Grading of the portfolios was based on timely completion and portfolio structure being a representation of a learning cycle, not on the specific content of that cycle. However, if they planned an activity in the 4th stage of the learning cycle, they were expected to carry that out for the next portfolio and reflect upon that. The near-peers were encouraged to be honest with themselves and take the time necessary to think carefully about their experiences. I prioritized building the near-peer's confidence and providing

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ideas and resources for them when they felt something didn't go as well as they would like. When they had ideas to overcome obstacles in the abstraction and experimentation sections, I encouraged them to carry them out.

I felt it was of crucial importance to express my own vulnerability when giving the near-peers feedback about teaching for the first time. I told the near-peers when I had a similar problem or expectation that did not go as planned at the beginning of my teaching career, and what areas I am still trying to improve in my teaching and learning. In this way, there are reciprocal models in place, by which the junior students felt supported and encouraged by knowing that the near-peers shared their struggles in learning, and the near-peers received the same feedback from me as the instructor. Example passages from a reflective portfolio by one of the near-peer students, the second author, are provided in the appendix.

The Benefits of Mentoring Near-Peer Teachers: The Instructor's Perspective

When this independent study was formed, my primary goal was to increase the faculty-to-student ratio, for a more structured, supported lab experience for the Anatomy and Physiology students at no additional cost to the department. At the same time, the experience could provide the near-peers with a unique method of earning credits while reinforcing their Anatomy and Physiology knowledge prior to entering their graduate programs. While the expected benefits were certainly achieved, there were a number of unexpected benefits and insights gained from the experience.

Benefits for the Anatomy and Physiology Students

As planned, having a near-peer join the instructor and graduate student in the lab decreased the student to faculty ratio from 18-1 to an average of 12-1. Informal feedback from the lab students and my own observations were that the lab students appreciated additional assistance, and were inspired by seeing someone one-two years older, who was successful in the course, now in a teaching role. The near-peers were transparent with the students in the amount of time they had to devote to Anatomy and Physiology, and were able to explain the significance of what they were learning in upper level courses.

Often, the lab students were required to prepare a short explanation or presentation for me in order to "check out" of lab, and they would frequently run their explanations by the near-peers first. In 2013, Anstey and colleagues published a reflection on a near-peer program developed for facilitation of guided inquiry projects in Anatomy and Physiology. They found that near-peers could be valuable facilitators of student inquiry due to their ability to relate to the junior students' feelings and needs for learning (Antsey et al. 2014). The Anatomy and Physiology students were able to see me interacting with the near-peers, and regularly asking the near-peers for feedback on how labs could potentially be improved.

A number of the Anatomy and Physiology students expressed interest in becoming a near-peer themselves in the following years. While they would not be the ones engaging with the new online laboratory options, the Anatomy and Physiology students were told that this critical review was part of the near-peers' role. Hopefully, this made it clear to the Anatomy and Physiology students that I was invested in their experience and open to feedback. Overall, the Anatomy and Physiology students were able to witness that mastery of the content they were learning was well within their grasp, and a model for how that can be achieved. This may be difficult to imagine when the only comparison a student has for their knowledge is the subject matter expertise of the instructor.

Benefits for the Near-Peers

Each of the four near-peers that signed up for the experience met all of the expectations that I set out for them. No one was late for a meeting, missed a day, or failed to submit their online laboratory reviews or reflective portfolios. Two of the near-peers, the senior students, were able to share their experiences in different formats. One near-peer did a presentation for the week of undergraduate excellence at the University, while another published the model he created for students to understand capillary exchange in the summer edition of the *HAPS Educator* in (Quinonez and Rompolski 2019). Through our conversations and content of their reflective portfolios, it was apparent that each near-peer greatly enjoyed the experience, felt that their understanding and recall of Anatomy and Physiology improved, and gained a perspective that they had not previously considered on the challenges of engaging with students and designing courses.

Every near-peer commented that having to figure out how to teach or explain a concept to others, especially when they are the authority in a setting, motivated them to better understand the material. The emotional charge of potentially seeming unprepared or unsure was a theme in all of their portfolios. A 2013 pilot program in which 4th year medical students in a senior radiology course were trained to instruct 1st year medical students in a series of anatomy sessions revealed that near-peers greatly enjoyed the experience and felt that their anatomical knowledge and teaching skills were improved by the experience (Naeger et al. 2013).

Perhaps most exciting to me as the instructor was that every near-peer was curious to find out how people go about becoming Anatomy and Physiology professors and thought that a clinical educator position could be part of their future career; something they had not previously considered. An interest in becoming teachers themselves is one of the benefits of near-peer teaching proposed by Neal Whitman in his 1988 piece "To Teach is to Learn Twice" (Whitman 1988).

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While there were common benefits seen for all four near-peers, each student had a unique goal, or area they wanted to improve upon, throughout the experience. One of these students described herself as being shy and afraid to speak publicly, so this was an opportunity for her to build her confidence in group settings before entering a clinical program in which she would have to teach her peers and educate patients. Another student had no difficulty in speaking with and engaging with the students but admitted to being easily distracted in school by social activities. The latter student's reflections frequently mentioned that the near-peer role was holding them accountable to me, the students and themselves in a way they had not experienced before in school, and how valuable that was for his professional growth. Two other students were preparing to attend medical school and a Physician Assistant Program and knew that gross anatomy and medical physiology would be rigorous courses within the first few months of their curricula. Thus, the reinforcement of material and new ways to learn and retain the material through teaching were valued preparatory experiences. While not related directly to the near-peer experience, working so closely with students over several months enabled me to provide strong letters of recommendation for all four of the students for graduate school.

Benefits to me as the instructor

Having an additional person to assist in the labs was a great benefit to me, since I sometimes felt that I could not support all the students to the degree that they deserved. Through this experience, I was able to closely mentor students for the first time on a consistent basis, which is an exciting career step for any educator. This mentoring experience required me to be open about my own struggles in teaching and learning, and receptive to both near-peer and Anatomy and Physiology student feedback. In fact, the idea for this experience was generated when one of the near-peers, the second author, requested to meet with the instructor while she was an Anatomy and Physiology student. From a place of curiosity, she asked me to explain why certain aspects of the course were designed the way that they were. This led to a productive conversation about the mismatch that can occur between instructor intentions and student perceptions, and the value of incorporating students into curriculum design.

Being a Near-Peer Teacher: The Near-Peer's Perspective

The following passage is told form the perspective of the second author, one of the near-peer students

"Dr. Rompolski's "near-peer" teaching experience allowed me the opportunity to not only observe and analyze how younger, undergraduate Anatomy and Physiology students learn, but also provided me a chance to further explore how I best learn in an education setting. I found it most effective to put myself in the students' shoes and complete the designed lab handout prior to my meetings with Dr. Rompolski. This provided me with a solid idea of what the students were expected to understand by the end of each lab. The first observation I made during my first lab experience was that most of them were reluctant to ask questions.

I soon realized that I needed to gain their trust and provide them with a sense of relatability in order for my time and theirs in the lab to be productive. I realized that this initial lack of trust in the beginning of the quarter was possibly due to the fact that I was an undergraduate student myself but was in a teaching position. I began to relate myself to them by making small remarks such as, "Oh, yes I remember this concept being very difficult to understand when I was in your year" in order for them to know that I once was exactly where they were. I then realized that so many professors at large education institutions miss this step. More often than not, gaining a student's trust is not very high on a professor's priority list. Dr. Rompolski ensures that students feel comfortable to ask them anything and this positively benefits their educational experience. Once students viewed me as a more seasoned version of "them", questions started to spill out in the cadaver lab and I was more than capable and eager to help.

In addition to providing the anatomy students with an older student they could trust, I believe that it was inspiring to them to see a professor have such confidence in an older student. Several different students towards the end of the quarter asked me how I earned this opportunity to aid Dr. Rompolski and if I had any advice for how they could achieve a similar experience. Having a near peer mentor in the lab created a strong incentive for students to further dive into their education.

It is evident that the near peer teaching experience was beneficial for the anatomy students, however it was equally (if not more) beneficial for me. Prior to this teaching experience, I was so accustomed to being in the student role and taking in all the information thrown at me and simply applying it to a quiz or test. In the beginning of the quarter, I noticed that when it came time for me to explain structures and

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their functions to Dr. Rompolski in our meetings, I initially experienced some difficulty. While I was sure that I knew concepts well, it was sometimes difficult for me to put them into easy-to-understand words. My objective when I explained things to students was to break the concepts down and hopefully make the anatomy easier to comprehend rather than confusing them even more.

I remember a specific example of this personal learning process when I was having a difficult time explaining Wiggers Diagram. Dr. Rompolski instructed me to draw my own diagram from the very beginning. She asked me to draw it piece by piece and attempt to explain each part along the way. I vividly remember the moment I realized that I did in fact know all the information; I just needed to show the students how to break down the concepts and reconnect them. I spent the entire cardiovascular lab circulating to different groups of students, asking them to break down the pieces of the diagram and explain them back to me. I was incredibly proud of myself. Furthermore, I learned that rather than talking *to* students, I needed to talk *with* them. The conversation needed to be interactive and two-sided to ensure they were connecting all the information and concepts. I learned that if I have really mastered the material, then I should be able to teach it. This is a lesson that I have steadily carried with me after my near peer experience came to a close, and is now the last step implemented into my study routine prior to exams.

This near-peer teaching experience was extremely beneficial to everyone involved. Learning to better understand student's perspectives and allowing them to feel a level of comfort when I was teaching was crucial for their learning experience. Learning how to verbally and visually teach students was crucial for my own personal learning experience. I believe that educational institutions would observe the increase in students' and professors' understanding of how students effectively learn and how professors effectively teach if near peer teaching experiences were routinely implemented."

Suggestions for Creating a Successful Undergraduate Near-Peer Program

At first glance, a near-peer program driven from elective course credit seems like a simple solution to problematic faculty-to-student ratios, or lack of funds or graduate TAs for additional laboratory support. However, implementation of a near-peer experience is not without careful planning and a significant time commitment for both the instructor and the near peers. General recommendations for creating and managing a near-peer program are presented next, which could easily be applied to any course or topics.

1. *Choose students who are genuinely excited to help other students.*
   This should be the first step, whether specific students are invited to consider a near-peer experience, or an application process is created. It will undoubtedly be difficult to accomplish any of the goals of the near-peer experience if the student is not eager to fulfill the role.
2. *Choose students who are enthusiastic about the subject matter.*
   As with #1, genuine interest in Anatomy and Physiology will be both a motivator for the near-peers to prepare for helping the students, and encouraging to students who are trying to understand the material. The near-peer teaching experience should only continue to increase the students' enthusiasm for the subject matter and motivate them to continue to learn Anatomy and Physiology in even greater depth.
3. *Choose students who were successful in the course with the closest social congruence.*
   While this criterion of having been successful in the course seems obvious, high grades do not suggest that the student would be an effective near-peer teacher, or are passionate about the subject matter. In fact, it may be beneficial to choose near-peers who initially struggled in the subject and overcame obstacles to learning, as they may be better able to relate to their junior peers. In addition, choosing students who are not too many years out from the course (ideally, one to two years) is important for social congruence (Loda *et al* 2019).
4. *Set goals and expectations that all near-peers must meet.*
   These can be unique to the institution or class in question, but a regular schedule of activities, and holding the students accountable for those activities, is vital to the success of near-peer teaching. Simply providing the near-peers with the lab materials in advance and expecting them to show up ready to teach is setting them up for failure and embarrassment, potentially leading to misinformation and anxiety in the students in lab, and creating more work for the instructor in the end; all of which are the opposite of the intent of near-peer teaching.

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It is strongly recommended that the instructor meet for a practice/mock run of the lab, during which time the near-peers must demonstrate mastery of the laboratory exercises and concepts to the instructor. The near-peers should also be required to take the same lab assessments and be trusted to not to share the content of those assessments with any junior students they may know outside of class. For example, one near-peer had a few junior sorority sisters in the A&P lab. The near-peer experience is also a great opportunity to develop professional behaviors such as timeliness of dress, professional boundaries, as well as effective communication skills.

5. *Set specific goals that are unique to what the near-peer hopes to achieve.*
Each student will have a unique history that led them to becoming a near-peer, with various strengths and weaknesses. The strengths of the student should be highlighted and encouraged however possible during the near-peer experience, but should not determine the activities in which the student engages. For example, putting the more outgoing near-peer as a demo, while having a shyer student work on lab setup or curriculum review would be doing them a disservice. Students should be encouraged to identify at least one goal for personal and professional improvement and utilize some form of regular reflection to monitor their progress.

6. *Be willing and able to put in the time.*
The time needed for this may vary significantly from student to student and lab to lab. Therefore, willingness and an ability to mentor the near-peer students until they are ready is vital to a positive atmosphere in the lab. Instructors need to be cognizant of the demands on their time, and realistic about the amount of time they would be willing to devote to near-peer mentoring and preparation for lab.

Previous publications on near-peer teaching have stressed the importance of formal and structured training programs for the success of a near-peer program (Antsey et al. 2013, Evans et al. 2011, Border 2017). For me, the instructor, the near-peer mentoring was a non-compensated overload in my schedule. I spent approximately three hours per week helping to prepare the near-peers for lab, and another three hours reading and providing feedback on their reflective portfolios and critiques of virtual labs. While at times challenging, the experience was very personally rewarding and well worth the time commitment.

Requiring near-peers to prepare thoroughly for lab, but not giving them the space to practice and receive feedback and correction prior to helping their junior peers, sets them up for anxiety, embarrassment and potential confusion in the lab. If near-peers are required to critically review curriculum material, the instructor should discuss this review with the students and solicit their suggestions.

Finally, if reflective practice of some sort is required, thoughtful feedback should be provided in a timely manner to reward students for their hard work and give them an opportunity to adapt before their next experience.

7. *Involve the lab students in the process.*
The junior students should be informed of the expectations set for the near-peer, and why the near-peer is a valuable resource in the lab. As mentioned previously, the students should be informed that the near-peers are not expected to know the answer to every question, and may have to come to the instructor for help. But, if they do answer a question or do not need instructor assistance, they can feel confident in the near-peer's response. This dynamic requires significant trust on the part of the instructor and students, and integrity and honesty in the near-peer, but with those dynamics in place, a very positive, collaborative environment is possible.

8. *Model the behaviors and attitudes expected***.**
Having near-peers in the lab, with the instructor providing guidance and modeling interactions with students until near-peers find their own unique voice or style of teaching, promotes professional behavior and a higher degree of accountability. Instructors should strive to be relatable to the students. This means being willing to admit mistakes, or when they do not know the answer to a question, so that the near-peers and students all feel safe doing so as well. Instructors should regularly share their rationale for what they ask students and request and embrace student and near-peer feedback, so that both groups feel that they have rapport with the instructor and that their contributions are respected. While the idea of involving students in decision-making or providing rationales for activities may seem like instructors are inviting students to criticize or question their authority, they are in reality utilizing inclusive classroom practices that work well for the current generations of college students (Ruzycki *et al*. 2019).

Conclusions/Future Directions

A well-designed and closely monitored undergraduate near-peer teaching experience can have a number of expected and surprising benefits for students, near-peers and instructors. Leveraging electives such as independent studies or senior research projects into near-peer teaching experiences can provide students with college credit while eliminating the burden of additional funding for graduate teaching assistants or faculty time for laboratory instruction. However, caution should be taken in the implementation of the near-peer program, particularly if availability or willingness to devote

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time is in question, both on the instructor and near-peer side. Regular feedback between the near-peer and the instructor is vital to the program and will benefit the near-peer far beyond confidence in the classroom.

Numerous publications suggest that near-peer teaching is enjoyed by all students involved, is beneficial for knowledge gains and teaching skills of the near-peers, and helpful to the students being supported by near-peers. However, research on the influence of near-peer teaching on other aspects of the teaching and learning environment, as well as consistent terminology defining a "near-peer", is needed (Olaussen et al. 2016).

A 2016 systematic review investigating how near-peer programs are assessed in undergraduate health professional education suggested that future research examine the quality of learning outcomes and focus on affective behavior and metacognitive skills gains. At the moment, much of the research on near-peer teaching and learning in Anatomy and Physiology comes from medical school anatomy classes, limiting its applicability to the traditional freshman or sophomore Anatomy and Physiology class. As more and more institutions adopt near-peer teaching at the undergraduate level in Anatomy and Physiology, efforts to recruit students from diverse populations, departmental investment in the growth of a program, and buy-in from other instructors involved in the curriculum are important considerations for the growth of near-peer programs. In addition, continuous evaluation of the effect of near-peers on student learning outcomes should be incorporated.

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Mackenzie Dallaire entered Drexel University as a freshman undergraduate student in 2016. She graduated with a Health Science bachelor's degree from Drexel University in March 2020. She will begin Physician Assistant School at the Philadelphia College of Osteopathic Medicine in June of 2020. She has aspired to play a significant role in the medical field ever since she was young and hopes to combine her love for medicine and providing healthcare to underserved communities in her career after graduating Physician Assistant School.

Literature Cited

Anderton R, Evans T and Chivers P. 2016. Predicting academic success of health science students for first year anatomy and physiology. *International Journal of Higher Education* 5: 250-260. https://doi:10.5430/ijhe.v5nlp250.

Anstey LM, Michels A, Szymus J, Law W, Edwin Ho MH, Qu F, Yeung RT and Chow N. 2014. Reflections as near-peer facilitators of an inquiry project for undergraduate anatomy: Successes and challenges from a term of trial-and-error. *Anat Sci Educ* 7: 64-70. https://doi:10.1002/ase.1383

Bulte C, Betts A, Garner K, Durning S. 2007. Student teaching: views of student near-peer teachers and learners. *Medical Teacher* 29(6): 583-590.

Dobson J. 2013. Retrieval practice is an efficient method of enhancing the retention of anatomy and physiology information. *Adv in Phys Educ* 37: 184-191. https://doi: 10.1152/advan.00174.2012

Durán CEP, Bahena EN, Rodríguez MdlÁG, Baca GJ, Uresti AS, Elizondo-Omaña RE and López SG. 2012. Near-peer teaching in an anatomy course with a low faculty-to-student ratio. *Anat Sci Ed*. 5: 171-176. doi:10.1002/ase.1269

Eagleton S. 2015. An Exploration of the Factors That Contribute to Learning Satisfaction of First-Year Anatomy and Physiology Students. *Adv in Phys Educ* 39:158-166. https://doi.org/10.1152/advan.00112.2014

Evans DJR and Cuffe T. 2009, Near-peer teaching in anatomy: An approach for deeper learning. *Anat Sci Ed* 2: 227-233. doi:10.1002/ase.110

Fraher JP and Evans DJ. 2009. Training tomorrow's anatomists today: A partnership approach. *Anat Sci Ed* 2: 119-125. doi:10.1002/ase.81

Gultice A, Witham A, Kallmeyer R. 2015. Are Your Students Ready for Anatomy and Physiology? Developing tools to identify students at risk for failure. *Adv Phs Educ* 39(2): 108-115.

Hopp R, Britson C, Mukhopadhyay S, Goldina A, Chapman M, and Nielsen M. 2019. Teaching Assistants in Human Anatomy and Physiology: Their Prevalence, Recruitment Strategies, Funding, Retention, and Training. *HAPS Educator*. 23 (2): 367-84.Published https://doi.org/10.21692/haps.2019.015

Irvine S, Williams B, McKenna, L. 2017. How are we assessing near-peer teaching in undergraduate health professional education? A systematic review. *Nurse Education* Today 50: 42-50.

Kolb DA. 1984. Experiential learning: Experience as the source of learning and development (Vol. 1). Englewood Cliffs (NJ): Prentice-Hall.

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Loda T, Erschens R, Loenneker H, Keifenheim KE, Nikendei C, Junne F, Zipfel S and Herrmann-Werner A. 2019. Cognitive and social congruence in peer-assisted learning - A scoping review. *PloS one* 14(9) https://doi.org/10.1371/journal.pone.0222224

McLeod SA. 2017. Kolb - learning styles. Available from: https://www.simplypsychology.org/learning-kolb.html

Naeger D, Conrad M, Nguyen J, Kohi M and Webb E. 2013. Students teaching students. *Academic Radiology* 20(9): 1177-1182.

Olaussen A, Reddy P, Irvine S and Williams B. 2016. Peer-assisted learning: time for nomenclature clarification. Med Educ Online 21 DOI: 10.3402/meo.v21.30974

Quinonez A and Rompolski KL. 2019. "Stringing Together" Capillary Exchange. *HAPS Educator* 23(2): 464-68. https://doi.org/10.21692/ haps.2019.018

Rees EL, Quinn PJ, Davies B and Fotheringham V. 2016. How does peer teaching compare to faculty teaching? A systematic review and meta-analysis. *Medical Teacher* 38(8): 829-837, DOI: 10.3109/0142159X.2015.1112888

Reyes-Hernández CG, Pulido JMC, De la Garza Chapa RI, Serna Vázquez RP, Alcalá Briones RD, Plasencia Banda PM, Villarreal Silva EE, Jacobo Baca G, de la Garza Castro O, Elizondo Omaña RE and Guzmán López S. 2015. Near-peer teaching strategy in a large human anatomy course: Perceptions of near-peer instructors. *Anat Sci Educ* 8:189-193. doi:10.1002/ase.1484

Ruzycki S, Desy J, Lachman N and Wolanskyj-Spinner A. 2019. Medical education for millennials: How anatomists are doing it right. *Clin. Anat*. 32: 20-25. doi:10.1002/ca.23259

Sturges D, Maurer T, Allen D, Gatch D, Shankar P. 2016. Academic Performance in Human Anatomy and Physiology Classes: a 2-year study of academic motivation and grade expectation. *Adv Phys Educ* 40:26-31.

Whitman, NA, 1988. Peer teaching: to teach is to learn twice. ASHE-ERIC Higher Education Report No. 4. Washington, DC: Association for the Study of Higher Education.

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Appendix 1:

Invitation to the Near-Peer Teaching Applicants

"The purpose of this independent study is to provide students with teaching and mentoring experience in Anatomy and Physiology. It is well understood that being able to teach and learning how to teach a subject, is effective for long-term retention of material. Therefore, having a better understanding of how learning happens should benefit students, regardless of their future programs of study or teaching aspirations! Students in this independent study will participate in a weekly laboratory experience with current Anatomy and Physiology students and serve as a "near-peer" mentor during these experiences. It is expected that this independent study will increase the confidence, professionalism and interpersonal skills of the enrolled students, while simultaneously supporting the Anatomy and Physiology students. The outcomes of this independent study have the potential to benefit other Anatomy and Physiology instructors, particularly those with increasingly large class sizes. Ultimately, the successful implementation of this experience will depend upon clear, regular communication between us. I expect you to be fully prepared for the laboratory experiences and meet all deadlines. In turn, I will mentor and support you as much as you need until you feel confident to step into the laboratory experience with the students."

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Appendix 2:

Same Reflective Portfolio Written by the Second Author, a Near-Peer Student

Concrete Experience:
"I tried to let students settle in and find a cadaver or model first before making myself available for help. Once students began to find their rhythm I started to circle around and ask groups if they had any questions. Some groups quietly shook "no" while other groups bombarded me with five questions at once. Answering their questions gave me the opportunity to be really hands on in my explanation whether it was in a cadaver's body or comprehensively going through a diagram. Once the time in the lab was over, students returned back to the classroom to take their quiz. I, along with the TA, would cover up the bodies, put the models away, and rearrange the chairs so that the lab was left cleaner than it was when we first showed up."

Reflective Observation:
"Another thing I struggled with is that I definitely felt like there was nothing I could do for the groups of students who never had any questions and stuck to themselves. I know now that this is a great opportunity to say, "okay great, let me quiz you" and "do you want me to ask you practice questions?" Involving students that didn't necessarily want to be was difficult for me. I think that another thing I struggled with was for the second lab I tried re-learn the lab handout from a student's perspective when I really needed to be refreshing on the information from a teacher's perspective. For example, I really felt like I knew all of the technical information regarding the cardiac cycle (as detailed as each mV number for action potentials on an ECG) but then when it came time to explain this information to Dr. Rompolski in our pre-lab I was stuttering to find my words and I started to lose my confidence. While I thought that I had prepared well for the lab, I had missed the most important part. I needed to be able to teach and easily put into words what I knew. I am extremely grateful that Dr. Rompolski recommended I try to draw my own Wigger's diagram because once I did that I took the time to explain it piece by piece to someone out loud and it made me realize I knew the information all along it was just about connecting the concepts on the diagram and putting it all together. I was so happy with myself when I was able to confidently spend the majority of lab 2 for both weeks explaining the Wigger's diagram to a student."

Abstract Conceptualization:
"I believe my biggest strength in the past four weeks of this experience is making myself relatable to the students. I found that it really helped when I would say "oh my goodness I remember I found this particularly confusing too when I took this lab". Often times after I would say that they would reply with "that makes me feel so much better". I think they found a sense of familiarity with me and were able to identify with me when I said this especially because now, as a near peer, I am able to confidently teach them what I used to find confusing a year ago. I would always reassure them that a lot of it is just constant repetition of the concepts and material so that they aren't just trying to memorize specific information for a quiz or exam. This often led to them asking me how I would prepare and study for Anatomy.

I shared that I would always read and annotate the chapter prior to lecture so I was always a week ahead in my notes and that I would write down each question I would get wrong on my first quiz attempts and go back into the book and explain why (a big part of it for me is just writing everything down). They told me that they found that really helpful and would sometimes admit that they would just zoom through the quizzes. I would personally sometimes feel like I was babbling on or explaining things in complicated terms, however I found multiple times that I would start explaining something to a person and then by the time I was finished I would look up and five more students were crowding around me listening to what I was saying. One time I asked a student who was behind me "Do you have a question?" and they replied "No, you're just really good at explaining this so I decided to listen". The first time that happened was honestly a really incredible moment for me and every time it happens it leaves me with the best feeling."

Active Experimentation:
"For the future labs I would really like to improve on two main things: engaging the students who don't like to ask questions and then also preparing more applicable examples to what we're learning. As I already mentioned in my reflection portion, in both labs one and two it is always the same groups of students who like to keep to themselves and don't like to ask any questions. While it is so much fun (yes, fun!) to spend thirty minutes talking to the groups who have a million questions because they are so enthusiastic about learning; I need to spend more time focusing on the students who don't want my attention.

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Dr. Rompolski suggested that I offer to quiz them, which I started to do in the last lab and that worked out well, so I plan to continue to do this. I plan to come up with practice questions before the labs and write them down so that when I ask them to get involved, I have questions ready to fire off and ask. I know that this will provide an opportunity for these students to realize that they maybe don't know as much as they think they should, and this will open up a discussion for me to help explain concepts. I also want to improve by including real-life examples in my teaching experience in labs. A great example of this is when describing Wigger's diagram in Lab 2, she explained that the maximum and minimum aortic pressure are the same blood pressures clinicians measure! This was such a genius concept to mention because she was able to connect why hypertension is so dangerous for someone's cardiac health. Ventricular ejection cannot occur until the pressure in the ventricle is greater than the pressure in the aorta. Therefore, if someone has very high aortic pressure then their ventricle is going to work much harder in order to exceed that pressure to allow the semilunar valves to open and for blood to be ejected. Providing a clinical reference to why it is so important to know this information was really effective for the students and I plan to incorporate more of these explanations in my near peer teaching experience."

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This committee has completed, tested and approved the HAPS Comprehensive Exam for Human A&P and is developing an on-line version of the exam.

CURRENT HAPS-I COURSE OFFERINGS

Courses are continually added to hapsweb.org, watch our Facebook and LinkedIn pages and our Twitter feed for the latest course announcements!

Spring 2020

Clinical Correlates in Physiology
(1 credit) February 4 - 25, 2020
Patrick Eggena, M.D.
Novateur Medmedia, LLC

View Syllabus

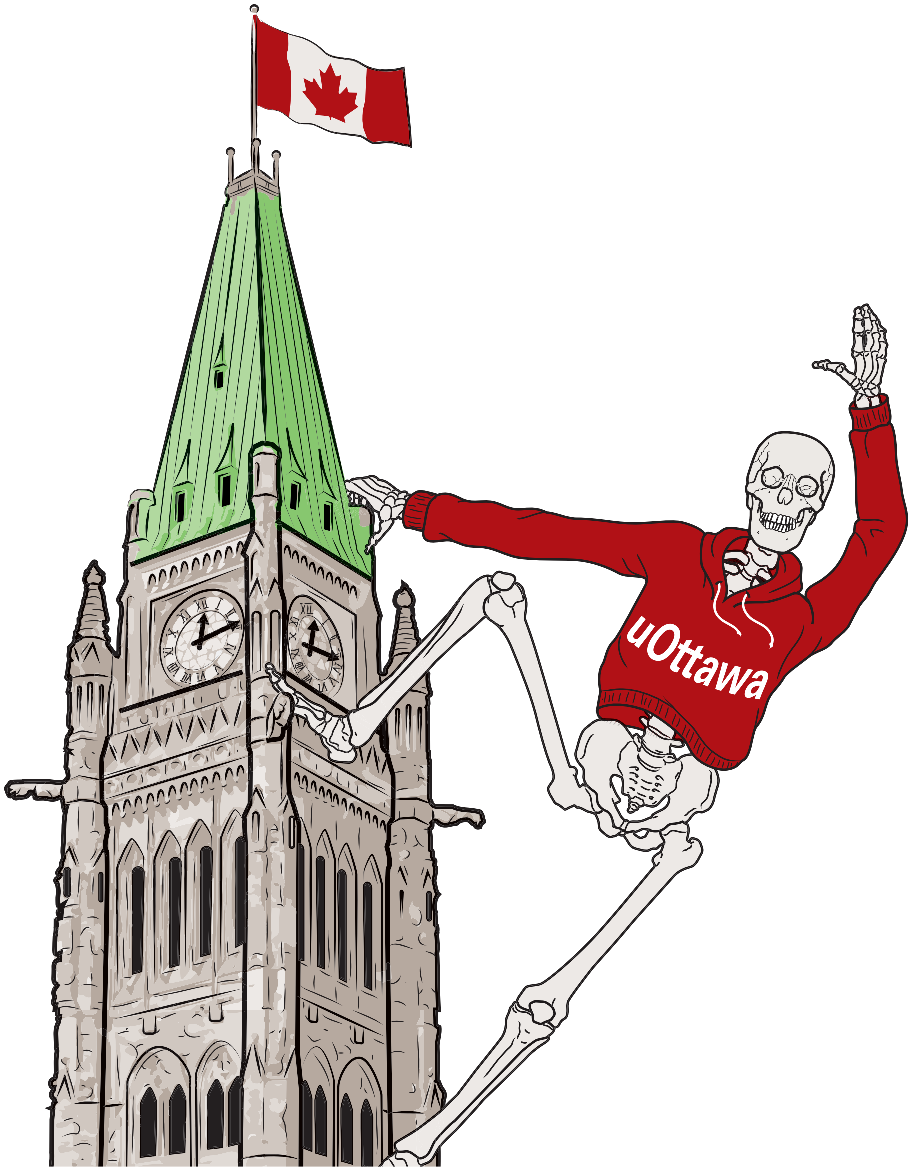
Click here to register for Graduate Credit or Professional Development

This course supplements the physiology of the heart, lung, and kidneys taught to pre-medical and nursing students by HAPS professors. In this course students are asked to put themselves in the role of a country doctor who is solving practical medical problems using this knowledge. This course reviews, integrates, and applies these basic principles in physiology. The philosophy of this course is that graphic essays are easier to grade than written essays and are better indicators of integration of knowledge than multiple choice exams. Therefore, in this course, exams are structured so that questions are answered primarily with graphs and drawings. In his weekly discussions, Dr. Eggena demonstrates with sketches, block diagrams, graphs, and equations how to answer essay questions in physiology. The students learn to visualize the problems and how to explain complex physiological processes in graphic form. A pool of 16 questions concerning the most important physiological topics is listed in the syllabus. Students practice for the exam by drawing answers to all 16 questions. Any four of these questions are then chosen by Dr. Eggena for a 2 hour proctored graphic essay exam.

HAPS 34TH ANNUAL CONFERENCE

MAY 23-27, 2020

CLICK HERE for more details!



HAPS 2020

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