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The HAPS Educator mourns the passing of Sarah Cooper

This edition of the HAPS Educator is dedicated to Sarah Cooper (1942-2021), a colleague, friend, and exemplary teacher, who was instrumental in bringing the HAPS Educator to anatomy and physiology instructors worldwide for many years. A long-time (1981-2021) faculty member at Arcadia University, Sarah was loved by her students for her kindness, her wisdom, and her ability to enrich their learning experiences.

Sarah began her association with the HAPS Educator as a member of the Editorial Board in 2011. In the summer of 2012, she took over as Co-Editor of the journal with Jennelle Malcos. She became Editor-in-Chief in 2015 and then continued her leadership role as Managing Editor from 2017 until her death in June of this year. Not only did she help new authors revise their manuscripts and bring them up to the quality we have learned to expect in the HAPS Educator, but she was also a regular contributor to the journal with informative and fascinating articles pertaining to the anatomy and physiology of not just humans, but other species as well. She will be greatly missed.

Since taking over as Editor-in-Chief last year, I worked closely with Sarah to produce each edition of the journal. She was always patient with my questions, an excellent communicator, and she had a helpful way about her that just made the editorial tasks easier to accomplish.

I would like to share with you some tributes to Sarah, from Kerry Hull, our past Editor-in-Chief, and from Katie Roberts, production and digital media UX.

Kerry: “The HAPS Educator owes its existence to Sarah! She was willing to fulfill any role that would promote the success of the journal, but also generously stepped aside when others wished to contribute. She loved choosing cover art, organizing the table of contents, and co-authoring articles with her students. She was an exceptional mentor, and I will be forever grateful that I was able to work with her so closely and for so long.”

Katie: “She [Sarah] was steady, and in this world where everything changes so quickly, she was one of those people who are like landmarks that make you happy to see and feel the familiarity. She was a joy to work with, and I sensed that one of her daily goals was to lift up the people around her, especially students. Her mentorship seemed to go beyond teaching, where unspoken actions were the valued example and living a life that wasn’t focused on self-advancement but rather helping everyone progress together, was the lesson. I will miss her. My days were always better each time I got an email tagged with, ‘I hope your day’s a good one.’ ”

It is hard to say good-bye. People like Sarah Cooper are truly gems when it comes to education. Her devotion to her profession was evident in everything she did, and I dedicate this edition of the HAPS Educator to her memory.

Jackie Carnegie, Editor-in-Chief
Implementing Guided Inquiry Active Learning in an Online Synchronous Classroom and its Impact on Test Question Performance

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Abstract
Guided inquiry is an active learning technique featuring collaborative group learning with a structured set of models and highly structured questions for students to discuss and answer. Moving this technique to an online delivery format presents challenges, leading to questions about the effectiveness of this technique during online instruction. This study looked at the synchronous online delivery of a sliding filament theory guided inquiry activity (Brown 2015) and scores on related exam questions in anatomy classes at Salt Lake Community College. Students who participated in the guided inquiry activity had a median score of 79% on questions related to the sliding filament theory of muscle contraction while those that did not participate in guided inquiry had a median score of 61%, revealing a medium effect on student test scores. This suggests that the guided inquiry activity was successful at improving student understanding and retention when delivered in the online teaching environment.

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Key words: guided inquiry, sliding filament, anatomy, muscle contraction, active learning

Introduction
Active learning techniques have been embraced by many STEM (Science, Technology, Engineering, Math) instructors to foster student learning. A meta-analysis performed by Freeman and coworkers in 2014 demonstrated that students are 1.5 times more likely to fail a STEM lecture-formatted class compared to a STEM class using active learning techniques (Freeman et al. 2014). The beneficial effects of active learning in biology courses were also found to be consistent with a failure reduction (Beck et al. 2014). They found that students performed 0.73 standard deviations (SD) better in biology laboratory courses with active learning than did students in a standard laboratory course (Beck et al. 2014). These positive outcomes may be related to the fact that active learning is especially beneficial for complex concepts such as those presented in biology and its subdisciplines such as anatomy and physiology (Jensen and Lawson 2011).

Guided inquiry is an active learning technique that features collaborative group learning with a structured set of models and questions for students to discuss and answer. A recent meta-analysis of 87 guided inquiry studies covering many educational subjects, including anatomy and physiology, demonstrated a positive impact on students’ content knowledge and the number of students earning A grades (Rodriguez et al. 2020). First adapted for chemistry Instruction (Farrell et al. 1999), guided inquiry has proven to be an excellent fit for biology courses (Armbruster et al. 2009).

Guided inquiry springs from constructivist learning pedagogy founded on the principle that knowledge is constructed, not transferred (Simonson 2019). Stated another way, knowledge must be constructed in the mind of each individual learner (Treagust et al. 1996).

Guided inquiry employs a learning cycle based on 3 phases of inquiry: exploration of the model (which can be a graph, or data, or a picture), concept invention, and application (Karplus and Thier 1967; Abraham and Renner 1986). The goal of this learning cycle is to help students make connections to their prior knowledge while they are building (inventing) this new concept so that it is more firmly stored in long-term memory (National Research Council 2000).

It has been shown with test results from chemistry students that guided inquiry improved retention of actively-gained knowledge when compared to a lecture-only group (Vanags et al. 2013). Jensen and Lawson (2011) demonstrated that guided inquiry is especially effective when teaching biology students who start the course with lower reasoning ability as measured by responses to higher cognitive level test questions. Although the use of guided inquiry to promote content retention in anatomy has not yet been tested, these studies on related content suggest that the use of this technique should benefit anatomy students.

Since many community colleges have open enrollment (no minimum ACT or SAT score), many students come to class without the experiential background that would benefit them
in anatomy. Additionally, community colleges have higher proportions of women and underrepresented minorities who are more likely to leave a STEM college major when faced with lecture-only classes (Rainey et al. 2019). Using active learning strategies in community college classrooms may be particularly beneficial for disadvantaged students. Haak and coworkers (2011) found that, while all introductory biology students benefited from an active learning, highly structured course design, the underrepresented minorities and economically disadvantaged students significantly closed the achievement gap when taught using this format.

Several studies have demonstrated use of guided inquiry during online instruction. One used guided inquiry as a home assignment with communication between class members occurring on a discussion board. The study evaluated their online conversations and demonstrated that the three stages of the learning cycle were occurring in this online environment (Lunsford 2008). A second study focused on the learning characteristics of students who chose guided inquiry over a video format and the ability of this educational method to promote belief change. Students with lower levels of academic entitlement, plus a growth mindset, did better with guided inquiry than with video (Barton and Chesley 2020).

It is unclear whether online delivery of guided inquiry will continue to foster topic retention and understanding as assessed using follow-up testing. This study used a two-group, post-test design to investigate this question in online synchronous anatomy classes at Salt Lake Community College.

**Methods**

**Student Population**

Salt Lake Community College (SLCC) is a large, multi-campus, public, two-year college located in Salt Lake County (population > 1 million). Approximately 60,000 students attend SLCC with 73% of those attending part-time. The average student course load is 6 class hours per semester. Forty-one percent of the students self-identify as working full time while the same percentage identify as working part-time. Fifty-four percent of the students self-identify as working full time while the same percentage identify as working part-time. Fifty-four percent are first-generation college students and approximately 75% receive financial aid, indicating the general fiscal status of this student population. The student population is 27% minority with Hispanic being the largest group. The average student age is 23; however, a wide range of ages is found in each classroom. This is an open enrollment school meaning no minimum ACT or SAT score is needed to apply. All students are evaluated for basic Math, Writing, and English skills before class placement. Each semester approximately 600-700 students take anatomy in classes limited to 30 students with two 80-minute class sessions a week. These students also take a separate 3 hours per week cadaver-based laboratory class that is limited to 24 students per section.

This study was carried out in a total of 6 online Anatomy lecture classes (3 in Fall 2020 and 3 in Spring 2021) taught by the same instructor (VFR). The prerequisite for anatomy is college biology, meaning students have some college experience prior to reaching the anatomy course. This study was approved by the IRB Board of Salt Lake Community College (IRB # 00009578, approved January 2020). No identifying student information was used in this study.

**Experimental Protocol**

Sliding filament theory is taught during the 6th week of class after students have learned the names of the axial and peripheral muscles. The sliding filament theory guided inquiry activity developed by Brown was used (Brown 2015). This activity includes four models: the sarcomere, the molecular events of the contraction cycle (including the ATP), calcium binding, and the neuromuscular junction. Both semesters it was announced, in advance, that classes given at 8:30 am and 1 pm would feature the guided inquiry learning activity. Students preferring a lecture format came to the 10 am class. Students self-selected for the guided inquiry activity, as much as their schedules would allow. A total of 40 students chose to participate in guided inquiry activities while 103 participated in standard lectures.

Fall 2020 classes were delivered on the Webex platform while the Spring 2021 classes were on the Zoom Platform. Both platforms allow breakout groups which were utilized for the small group interactions (3-4 students each). Students were assigned to their groups by the online platform and neither the students nor the instructor influenced group makeup. Students remained in the same group for the whole activity. Both platforms allow the instructor to "break in" to a group in progress and allow the group members to call for help. During the guided inquiry activity, students were in their group 4 times; each time for 7 to 15 minutes. Between group sessions, the entire class participated in defining the concepts and instructions for the next breakout. The instructor visited each group during the first breakout and then only when requested by the students.

Two weeks later, all students completed a test that included questions related to the sliding filament theory. The sliding filament questions represented about 17% of a section test covering 6 book chapters and 7 class periods. All questions were written by the instructor. The test was administered online through the Canvas Learning Platform using the Proctorio online proctoring program. The points earned by each student on the related questions were divided by the total points available on this topic to create a percent correct for each student. Test questions covered a range of difficulty from memorization to application of the concepts. (Appendix 1).
Data Analysis
Analyses were carried out using Jamovi, an open-source statistical software version 1.8.1 (www.jamovi.org). All tests were evaluated against an alpha level of 0.05. The distributions of grades in the guided inquiry and traditional lecture groups were first inspected for normality using the Shapiro Wilk test. Distributions deviated significantly from normal in the guided inquiry group (Shapiro-Wilk W (39) = 0.93, \( p = 0.01 \)) and the traditional lecture group (W (102) = 0.93, \( p < 0.001 \)). Levene’s test indicated non-homogeneity of variances (\( F (1, 141) = 11.8, p < 0.001 \)). As a result, group differences in grades were analyzed using the non-parametric Mann-Whitney \( U \) test, and effect size was estimated using rank biserial correlation.

Results
As shown in Figure 1, students participating in the guided inquiry activity (n=40) had a median score of 79.0% (mean = 77.0% ± 19.7 (SD)) on the topic questions. This was compared with a median score of 61% (mean = 61.4% ± 27.9 (SD)) for the lecture students (n = 103), a difference that was significant (\( U = 1389, p = 0.002 \)). A rank biserial correlation of 0.33 suggested that this was a medium-sized effect. In addition, no students receiving guided inquiry instruction received a grade in the lower 2 quartiles in contrast to students in the traditional lecture group (Figure 2).

![Figure 1. Comparison of median and mean (+/- 95% confidence intervals) grades received by students in the lecture condition (n = 103) and the guided inquiry condition (n = 40), indicating a significant difference (p = 0.002) in student outcomes between the two conditions.](image)

![Figure 2. Distribution of grades (%) received by students in the two online classroom conditions. Orange bars represent students in the lecture-only condition (n = 103) whereas blue bars represent students in the guided inquiry condition (n = 40).](image)
Discussion
Anatomy and physiology classes are often high stakes courses for students because they act as gatekeepers to entering a healthcare curriculum. A new vocabulary must be learned, and there are a tremendous number of structures to memorize and difficult concepts to master. Students entering with low academic self-efficacy can struggle with the demands of this subject and their confidence in achieving a good grade. The guided inquiry active learning approach presents an opportunity to help these students gain confidence within a group of peers and in their ability to understand the concepts. The current study, though limited in student numbers, indicates that students retained knowledge better after guided inquiry than from standard lecture, likely due to the exercise of constructing knowledge instead of aiming to learn it passively. After the guided inquiry activity used for this study, students expressed a desire for more such activities.

Several challenges specific to online learning were encountered with the implementation of guided inquiry. During an in-person guided inquiry activity, the instructor can walk around the class unobtrusively listening and lending guidance to student groups who are struggling or are off-topic. There is an organic nature to the interactions. In contrast, during the online activity, the instructor cannot hear the breakout groups. Joining a group creates an abrupt break in the student discussion. Consequently, the instructor joined each group only once during the first breakout session. In addition, not being able to hear the students means a guess must be made as to when to end the groups.

Several caveats need acknowledgment. Students who did not attend class could later watch a video of the lecture-only class. For those in the guided inquiry activities, however, videos of breakout groups were not recorded and thus these class videos weren't available later to students. This contributed to the larger number of lecture-only students (n = 103) who didn't attend class but later watched the lecture. Students receiving guided inquiry instruction could also have reviewed the lecture video on their own, however, review of the zoom recording analytics indicates that they did not. Additionally, students self-selected for the guided inquiry activity which may have influenced the grades if academically stronger students disproportionally opted for the guided inquiry activity. Students viewing the guided inquire recorded grades in all but the bottom quartile suggesting a good mix of students. All these considerations may or may not confound the data presented.

Conclusion
The abrupt transition to online learning led to new questions about the efficacy of guided inquiry in the online teaching environment. This active learning method has long and reliable evidence-based support for improving student scores, retention, and class engagement in a variety of basic sciences as described in the introduction. This study also supports using guided inquiry in an online environment to benefit student retention of content, this time for the study of anatomy.

About the Authors
Vicky Rands is an Assistant Professor at Salt Lake Community College where she teaches Anatomy and Physiology to students focused on healthcare careers. She is a participant in the CAPER -NSF Grant research project coordinated by Murray Jensen, a professor at the University of Minnesota where he teaches entry-level physiology and conducts research on teaching and learning. Suzanne Hood is an Associate Professor in the Psychology Department at Bishop's University. Her research interests include how individual differences in psychological states affect academic performance. Ron Gerrits is a professor at Milwaukee School of Engineering. He is acting as a mentor in the CAPER project.

References


APPENDIX: Test Questions on Sliding Filament Theory

1. The primary function of the T-tubules is to:
   - Allow for the generation of new muscle fibers
   - Allow the muscle membrane impulse to move deeper into the cell
   - Finish the muscle fiber contraction
   - Provide nutrients to the muscle fiber

2. Which of the following is not associated with the thin myofilament?
   A. Actin
   B. Troponin
   C. Tropomyosin
   D. Myosin

3. At the neuromuscular junction, all of these are true except:
   A. The muscle impulse continues along the sarcolemma and down the T-tubules.
   B. The synaptic cleft is the space between the nerve and the muscle.
   C. The synaptic vesicles contain the neurotransmitter norepinephrine.
   D. The receptors are located on the motor end plate.

4. What is attached to the thin filament in the sarcomere?
   - Endomysium
   - Z-line
   - M-line
   - Thick filament

5. What happens when ATP binds myosin?
   A. Myosin binds troponin.
   B. It releases from actin.
   C. The myosin changes shape.
   D. The power stroke occurs.

6. All of these are true about the role of ATP in muscle contraction EXCEPT:
   A. ATP hydrolysis to ADP and Pi moves myosin to the cocked position.
   B. ATP binds myosin.
   C. When myosin bound to actin releases the ADP, the power stroke occurs.
   D. ATP allows calcium to bind to troponin.
7. The ______ [Select] is the contractile unit inside the muscle fiber. This unit is made up of three parts. The ______ [Select] filament is attached to the ______ [Select] which is the vertical “side” lines. The ______ [Select] filament only attaches to the ______ [Select] when it is forming the cross bridge. 

ANS 1 choices: sarcomere, sarcolemma, sarcoplasmic reticulum, myofibril
ANS 2 choices: thin, thick, M-line, Z-line
ANS 3 choices: Z-line, M-line, thick filament, thin filament
ANS 4 choices: thick, thin, small, large
ANS 5 choices: actin on the thin filament, troponin on the thin filament, Z disc protein

8. Put the steps of muscle contraction in order. Note: Some of the steps are listed for you! (For questions in italics, supply dropdown menu for students to choose correct answer)

1. An electrical impulse travels down the nerve fiber
2. A nerve impulse causes vesicles to release Acetylcholine into the synaptic cleft
3. Ach binds to receptors on the muscle membrane causing the electrical impulse to be transmitted to the muscle membrane
4. The electrical impulse inside the muscle cell causes the release of calcium ions from the sarcoplasmic reticulum
5. Ca++ ions bind troponin
6. Troponin rotates and moves tropomyosin off of the myosin binding site on Actin.
7. The myosin head binds the actin binding domain.
8. Myosin bends in two places, releasing ADP and pulling on the thin filament
9. The Z-lines are pulled closer together and the sarcomere gets shorter
10. The myofibril contracts
Does a Student’s Academic Major Influence Their Perceptions of a Human Anatomy and Physiology Course and Ultimately Their Success in the Course?

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Abstract
Students from a variety of majors take human anatomy and physiology courses—usually because they are required for their program of study. Many students find anatomy and physiology classes academically challenging and institutions across the country report high failure and withdrawal rates for these courses. Although research has shown that several factors may contribute to poor student performance, this study focused on the relationship between a student’s major and their perceptions about the course to investigate whether these data were reflective of student success rates. Survey data was collected from students in the first semester of a two-semester, systems-based human anatomy and physiology course sequence. While the results did not show a statistical difference in successful completion of the anatomy and physiology course related to academic major, interesting preferences regarding learning styles, study habits, and perceived difficulty of the course were found.

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Key words: anatomy, physiology, academic major, learning styles, study habits, perceptions

Introduction/Background
Anatomy and physiology (A&P) courses, which are required as foundational courses for many degrees, often act as bottleneck courses because they have some of the highest rates of failure and withdrawal from courses at the undergraduate level (Harris et al. 2004; Higgins-Opitz and Tufts 2014; Hopper 2011; Sturges et al. 2016). Students must learn a large amount of new terminology, memorize a staggering number of anatomical structures, and comprehend the physiological processes of multiple organ systems—typically at the freshman or sophomore level of their education (Sturges et al. 2016; Wehrman et al. 2020). However, studies by Anderton and colleagues (2016a) and Sitticharoon et al. (2014) found that students who mastered the skills needed to succeed in A&P often achieved success in other college courses as well, leading to higher overall grade point averages (GPAs). Considering the importance of GPA to acceptance into many health-related programs and the fact that many programs use A&P grades specifically as a criterion for acceptance, it must be agreed that A&P courses are important for the advancement of students in multiple health professional programs.

Much work has been done to investigate demographic factors that may influence student success in A&P courses including age, gender, and ethnicity (Gultice et al. 2015; Russell et al. 2016; Schutte et al. 2016; Gwazdauskas et al. 2014; Vitali et al. 2020). In addition, academic factors that can predict success have been studied, including foundational skills, placement test scores, and prerequisite requirements (Esmat and Pitts 2020; Forgey et al. 2020; Hull et al. 2016; Shaffer et al. 2018; Schutte 2016; Taylor 2005; Wehrman et al. 2020). In particular, some researchers have found that students who have completed a prior college-level anatomy or physiology course are more successful than other students when the A&P class grades are calculated (Esmat and Pitts 2020; McCleary et al. 1999; Shaffer et al. 2018; Wehrman et al. 2020).

Several studies have looked at the implications of a student’s chosen major and how this might be involved in student success — particularly regarding prerequisite courses specific for each major and the level of motivation to complete the major and perhaps be successfully admitted into a health-related program of study (Esmat and Pitts 2020; Higgins-Opitz and Tufts 2014; Reinke 2019; Rompolski et al. 2016; Schutte 2016; Sturges et al. 2016; Wehrman et al. 2020). For example, studies regarding the exercise science major, also known as sport science or exercise and sport science, suggest that students in this major may be less successful in A&P than students in other majors (Esmat and Pitts 2020; Higgins-Opitz and Tufts 2014; Reinke 2019; Schutte 2016). The same inference has been made regarding students in two- and four-year allied health degree programs, such as nursing, dental hygiene, and other programs with similar course requirements (Rompolski et al. 2016; Shutte 2016). Other studies have shown that students in pre-professional majors, such as biology or health science, have been more successful in A&P courses compared to their classmates in other majors (Gwazdauskas et al. 2014; Shutte 2016).
Researchers have considered the relationship between academic performance in A&P and students’ perception of these courses, including their motivation to study and their initial perception related to the difficulty of the courses (Royse et al. 2020; Slominski et al. 2019; Sturges and Maurer 2013; Sturges et al. 2016). To evaluate student perceptions, several measures of study habits may be evaluated, including learning styles or strategies, time devoted to study, study techniques, and perceived difficulty of the course, both before and after completion of the course (Breckler et al. 2009; Fleming 1995; Husmann and O’Loughlin 2018; Knight and Smith 2010; Quinn et al. 2017).

Learning styles are described as a set of factors, behaviors, and attitudes that facilitate learning for an individual in a given situation (Quinn et al. 2017). The concept and existence of student learning styles has been a subject of great discussion and debate in educational research, likely due to a lack of correlation among teaching methods, learning styles, and student outcomes (Husmann and O’Loughlin 2018).

Learning styles group common ways that people learn and there are as many as 71 different learning style tools and theories (Knight and Smith 2010; Quinn et al. 2017). For example, student learning may be classified according to the sensory modalities that one most prefers to use when studying material. One such classification scheme uses Fleming’s VARK instrument (Fleming 1995), which categorizes learning preferences as visual (V), auditory (A), reading-writing (R), or kinesthetic (K). However, even its developer noted that there are limitations to the scope, validity and reliability of the VARK questionnaire (Breckler et al. 2009; Fleming 1995).

The VARK model was originally developed as a tool to promote discussion and reflection on learning styles (Fleming and Mills 1992; Husmann and O’Loughlin 2018). Fleming reminds us that the VARK was never meant to be a diagnostic tool. Indeed, only 15.5% of all students were able to accurately self-predict their own VARK result (Breckler et al. 2009; Husmann and O’Loughlin 2018). However, the VARK learning philosophy at least offers and encourages teachers to acknowledge that there are learning differences and to make efforts to address some of these differences in their classrooms by attempting a wide range of teaching approaches (Dunn and Griggs 2003).

At the undergraduate level there is a noticeable lack of research on learning style preferences of students enrolled in gross anatomy classes. The literature in this area is mostly focused on learning style preferences among medical students (Anderton et al. 2016b; Knight and Smith 2010; Quinn et al. 2017). The purpose of this research study was to address the following research questions in the context of survey data from students in a variety of different majors and academic plans enrolled in the first semester of a two-semester, systems-based A&P course sequence:

1. Does a student’s major or academic plan influence their overall success in an A&P course?
2. Does a student’s major or academic plan influence their learning style preferences, study techniques, and time spent studying when taking an A&P course?
3. Does a student’s major or academic plan influence their perception of the difficulty of an A&P course?

Methods

Study Context and Participants

This project was conducted at Frostburg State University (FSU), which is a comprehensive, regional public liberal arts university in Western Maryland. FSU is part of the University System of Maryland (USM) and is the only four-year public institution in the state west of the Baltimore-Washington metropolitan area. It serves as the educational center for Western Maryland and surrounding counties in Pennsylvania and West Virginia and typically enrolls 4,700 to 5,000 undergraduate and graduate students each year.

In this study, students enrolled in human A&P I, which is the first of a two-semester, systems-based human anatomy and physiology course sequence, were surveyed at the beginning and just before completing the course in fall 2016 and fall 2017. There were a total of 306 students enrolled in both sections at the beginning of the two semesters and 282 students completed the course with 24 student withdrawals. Students who took this class were required to have the first introductory biology course (Biology 149 at FSU), or the equivalent, before they were permitted to enroll, so most were sophomores (n=163). However, some were freshman (n=46) who had completed an equivalent course prior to enrolling at FSU, and some were juniors (n=76) or seniors (n=21). The project was approved by the Frostburg State University Institutional Review Board (FSU Project #H2016-001), and informed consent was obtained from all participants. Student participation was voluntary and anonymous and had no influence on course grades.

Description of Survey Questions

All students in the class were asked to complete two anonymous, in-person, paper surveys (Appendix 1). There was no time limit for either survey. The initial survey was administered at the beginning of the semester during the second week of class, and the final survey was done near the end of the semester during the second-to-last week of class before final exams. Note that the final survey was completed after the course withdrawal deadline (week 10), so students who withdrew from A&P I in 2016 and 2017 (n=24) were not represented. A total of 294 students from both sections in both years completed the initial survey (96.08%) and a total of 248 students from both sections in both years completed the final survey (87.94%).

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The first set of survey questions, classified as descriptive questions, asked about a student’s major or academic plans, career goals, and if they had taken any previous A&P courses at the college level. At FSU, students in several different majors and academic pathways take both A&P I and II. The majors include biology, chemistry, health science (pre-medical, pre-dental, pre-physician assistant, pre-physical therapy), exercise and sport science, and athletic training. Students with other academic plans include transfer students (pre-nursing, pre-dental hygiene, pre-occupational therapy), and students enrolled in other majors, such as psychology, or undecided students, that take the course for a variety of personal and academic reasons. Career options that students could select included personal trainer, athletic trainer, health profession at the bachelor’s level, master’s level, or doctorate level, research or academic position at the master’s level or doctorate level, or ‘other’ for those with other career goals or who were still undecided.

In the final survey, students were asked if they changed their major or academic plan and/or career goal during the semester. It’s important to note that the population of students at FSU is represented by differences in age, gender, and cultural and educational backgrounds; however, we did not collect demographic information regarding these parameters on either survey to help maintain student anonymity.

The second set of survey questions, classified as preference questions, asked about a student’s learning style preferences, study techniques, time spent studying, and perceived difficulty of the course. Students were asked about their learning styles, or modalities, by using those outlined in the textbook used for the course (Amerman 2015). Similar to the VARK assessment, our survey included four sensory modalities: Visual/Verbal, in which learners fare best when reading written material such as notes and textbooks and looking at diagrams, illustrations, and visual multimedia presentations (such as animations); Visual/Nonverbal where learners best understand concepts through the use of diagrams, illustrations, and other visual media without text; Auditory/Verbal, in which a learner does well when listening to lectures, presentations, or when discussing material with a group (these individuals tend to prefer text-based materials rather than visuals); and Tactile/Kinesthetic where the learner thrives in an environment where he or she can physically manipulate a specimen (these students excel in practical settings, including the A&P lab) (Amerman 2015).

Unlike the VARK assessment, which compares the proportion of multimodal learners (those that have strong preferences to using multiple learning styles) to unimodal learners (those that have a single, strong preference), the survey used in this study attempted to limit students’ responses to the single learning style they most strongly preferred. In the final survey, students were also asked if they believed that they had a different learning style than they selected on the initial survey. Two additional questions asked about students’ plans to use the same study techniques that they used for other courses, and how much time they planned to study for the A&P I course compared to other college courses. Students were asked these questions again on the final survey to see if they changed their answers. Finally, on the initial survey, students were asked how difficult they thought the class would be, and on the final survey, students were asked how difficult they actually found the class to be. This data was collected using a scale of 1-10, with 1 being very easy and 10 being the most difficult.

Data Analysis

For the purpose of evaluating the data relative to previous studies and for statistical comparisons, students were sorted by major or academic plan into three academic groups: Kinesiology (n=120), which included exercise and sport science and athletic training majors; Science (n=142), which included biology, chemistry and health science majors; and, Miscellaneous (n=44), which included students with alternative academic pathways, such as transfer students, other majors, and undecided students.

Student success was evaluated by comparing the final grades of students by their academic group and by their class standing. Frostburg State University uses the standard letter grading system of A, B, C, D, F, and W for students who withdraw before the class is completed. No “+” or “-” additions to the letter grades are reported. Students who received D, F, or W grades were considered unsuccessful in the course. Graphic results comparing initial and final survey data from the three academic groups are reported as percentages to account for the reduced number of students completing the final survey. Chi-square tests for independence were used to compare initial and final survey responses between the three academic groups and to compare student success between the three academic groups and by class standing. Significance was set at $p \leq 0.05$.

Results

Descriptive Questions

Academic Major or Plan

The percentage of students enrolled in each major or academic plan did not significantly change ($p = 0.91$) from the initial to the final surveys (reported as initial percent; final percent). The most popular majors or plans were exercise and sport science (31.3%; 26.2%) and health science (27.0%; 28.5%), followed by biology (18.3%; 18.8%), transfer students (8.7%; 9.6%), athletic training (7.3%; 8.5%), ‘other’ (5.3%; 6.5%), and chemistry (2.0%; 1.9%). It should be pointed out that in 2016 and 2017 when the surveys were completed, the athletic training major was offered at the bachelor’s level at FSU. It has since become a master’s level program and students enroll in

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...the exercise and sport science undergraduate major to prepare them for the graduate level athletic training curriculum. The fact that there were no significant changes in number for any major from the initial to final surveys justified our use of academic groups for statistical analyses.

**Career Goals**

Overall, the most popular career goals in both the initial and final surveys (reported as initial percent; final percent) were those in the health professions, particularly at the doctorate level (51.7%; 46.6%) and master’s level (20.5%; 19.0%). These were followed by health professions at the bachelor’s level (7.9%; 11.5%), ‘other’ (6.3%; 8.6%), personal trainers (6.9%; 6.1%) and athletic trainers (4.1%; 5.7%). Very few students selected research or academic positions at the doctorate (1.6%; 1.1%) or masters levels (0.9%; 1.4%). Again, the percentages in each career goal did not change significantly (p = 0.59) from the initial to the final survey.

When comparing the career goals of each academic group, there were differences in the popularity of the options. For example, only students in the Kinesiology group selected personal and athletic trainer careers. The few students who selected one of the research or academic options were in the Science group and the majority of students who selected health professions at the bachelor’s level were in the Miscellaneous group. Students in both the Kinesiology and Miscellaneous groups also selected ‘other’ as possible career options.

**Previous Anatomy and Physiology Courses at the College Level**

Students were asked if they had taken a previous A&P course at the college level and the majority replied that they had not. When comparing the responses by academic group, there was a statistical difference (p = 0.003) with 84.3% of Science students reporting that they had not taken a prior A&P college course, compared to 69.6% of the Kinesiology students and 62.2% of the Miscellaneous students. Students were not asked whether the prior A&P course was at FSU or another institution or whether they were repeating the course. No questions were asked about prior A&P courses taken in high school.

**Perspective Questions**

**Learning Style Preferences**

The most popular learning style preference (LSP) in both the initial and final surveys across all three academic groups was Visual/Verbal. More than half of all students selected this modality on the initial survey. In the final survey, the percentage of Kinesiology students who preferred Visual/Verbal fell about 7% with a smaller decline in the Miscellaneous group. This is in contrast to the Science group, where nearly 65% of students on the final survey preferred Visual/Verbal compared to 50% on initial survey. The second most common LSP was Tactile/Kinesthetic on both surveys in all three academic groups, with Kinesiology students showing a slightly stronger preference for this learning modality as compared to the Science and Miscellaneous groups although the preference did increase in the Miscellaneous group in the final survey. Coming in third and fourth, respectively, for both the Science and Miscellaneous groups were Auditory/Verbal and Visual/Nonverbal on both surveys. In contrast, students in the Kinesiology group preferred Visual/Nonverbal over Audio/Verbal in both surveys (Figure 1).

![Figure 1. Learning style preferences by academic group expressed as percent of students completing initial and final surveys.](image-url)
It is noteworthy that, although asked to provide “which method of learning best describes your learning style” on both surveys (reported as initial percent; final percent), a proportion of students in all three groups selected multiple learning styles. Although this increase was not statistically significant (p=0.44), the largest increases in multimodal learners were in the Science (9.9%; 18.8%), and Miscellaneous (9.5%; 16.7%) groups, where those selecting multiple learning style preferences nearly doubled. The percentage of students in the Kinesiology group selecting multiple learning styles (12.1%; 14.4%) was similar in both surveys.

**Study Techniques**

In the initial survey, students were asked if they planned to use the same study techniques for A&P I that they had used in other college classes. While nearly 60% of all students predicted that they would, in the final survey, only about 40% of all students did ultimately report using the same study techniques in A&P I as they had in other college courses (Figure 2). Although the percentage of Science students appeared most likely to maintain the same study techniques, there was no statistical difference (p = 0.052) when comparing their initial and final responses. Meanwhile, over 20% of Kinesiology students reported using different study habits in A&P I than they had predicted, which was statistically significant (p = 0.0007). A similar trend was seen with the Miscellaneous students, which was also statistically significant (p = 0.04).

**Study Time**

In the initial survey, students were asked to predict the amount of study time they would devote to A&P I compared to other college courses they had taken. Students in all academic groups overwhelmingly reported (80% or above) that they would spend more time studying for A&P I than they had for other courses. No student predicted that the time would be less. Less than 10 per cent of students in each of the Kinesiology and Miscellaneous groups predicted that they would spend about the same time studying for A&P I as other classes whereas almost 20% of Science students believed that they would invest the same amount of time (Figure 3).

When asked on the final survey how much time they actually spent studying A&P I compared to other courses, over 90% of Kinesiology students did report studying more for A&P I than for other classes and those that invested about the

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**Figure 2.** Study techniques (same or different) compared to other college courses by academic group. Percent of students completing initial and final surveys.
same amount of time increased slightly (Figure 3). Students in the Miscellaneous category more accurately predicted that they would spend more time studying A&P I, although some students did report actually spending less time with A&P I than other courses. Students in the Science group reported that they spent less time studying A&P I compared to other classes than they initially predicted. However, within the academic groups, there was no statistical difference between the initial and final surveys (Kinesiology $p = 0.18$; Science $p = 0.30$; Miscellaneous $p = 0.67$).

Figure 3. Study time (more, less or the same) compared to other college courses by academic group. Percent of students completing initial and final surveys.
Perceived Difficulty of the Course
In the initial survey, students were asked to rate on a scale of 1 to 10 how difficult they expected the course to be with 1 being very easy and 10 being most difficult. Similarly, in the final survey, students were again asked to rate the difficulty of the course and whether they felt the course was easier or harder than they had thought it would be. The most frequently chosen numerical answer, or mode, on both the initial and final surveys among all academic groups was 8/10. This result is interesting considering that 60% or more of students from all three academic groups stated that they felt the class was harder than they thought it would be.

Student Success Rates
As reported previously, a total of 306 students were enrolled in both lecture sections of A&P I in 2016 and 2017. A total of 95 students (31.0%) were unsuccessful and either withdrew ‘W’ or received a ‘D’ or ‘F’ grade for the course. When comparing the DWF grades by academic group (close to 30% for each group), no statistical significance ($p = 0.90$) was found (Figure 4).

Figure 4. Class composition (kinesiology, science, other) and percent students with DWF (grade of D, withdrew from course, grade of F) by academic group and as percent of the entire A&P class.
The majority of students in A&P I were sophomores, followed by juniors, then freshman, and, finally, seniors. Although comprising only 15% of the course, freshmen accounted for nearly a quarter of the course DWF grades. Almost 48% of freshmen were unsuccessful in the course, followed by sophomores at just over 33% and seniors and juniors at about 19% (Figure 5). Class-standing was found to be correlated with successful completion of this A&P course ($p = 0.004$). However, students were not asked to self-identify by class standing so no survey data could be directly related to this parameter.

**Figure 5.** Class composition by standing (freshman, sophomore, junior, senior) and percent of students with DWF (grade of D, withdrew, grade of F) by class standing and as percent of the entire A&P class.

**Discussion**

**Descriptive Questions**

**Academic Major or Plan**

As is the case with many institutions, the A&P I course at FSU is a required course for students in a variety of academic majors and plans, so we were interested to see if students changed their major or plan after taking the course. While some students did change their major or plan during the semester, the numbers were not statistically significant.

**Career Goals**

The most popular career goals in both surveys were those in the health professions, which is not unexpected from students enrolled in a human anatomy and physiology course. In addition, certain career goals that were selected exclusively or almost exclusively by specific academic groups also were expected. Even though there were no statistically significant differences between the surveys, a trend toward a decrease in selecting the option of health profession at the doctorate level by Kinesiology and Science students may indicate that some students were reconsidering their career options after taking the A&P I class.

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**Previous Anatomy and Physiology Courses at the College Level**

While most of our students had not taken a previous A&P course at the college level, there was a statistical difference regarding the number of students by academic group. Unfortunately, we do not know if the students who had taken a prior college level A&P course were repeating the course or had taken a different A&P course, such as a single-semester, essentials of A&P course. It is noteworthy that there was no significant difference in student success rates for any of the academic groups which suggests that a prior A&P course at the college level was not helpful in this regard. It is unclear, then, whether our results agree or disagree with other studies (Esmat and Pitts 2020; McCleary et al. 1999; Shaffer et al. 2018; Wehrman et al. 2020).

**Perspective Questions**

**Learning Style Preferences**

Our findings on preferred learning styles among students in A&P I are contrary to other studies reporting that a majority of students enrolled in A&P prefer a kinesthetic, or hands-on approach, to learning (Anderton et al. 2016b; Breckler et al. 2009; Carnegie 2008; Hsieh et al. 2012; Meehan-Andrews 2009). Students in our study most commonly selected a Visual/Verbal learning style ahead of a Tactile/Kinesthetic approach. However, only about 5.6% of students overall noted that they identify with a different learning style preference altogether than what they had indicated on their initial survey. It was noted that students in the Kinesiology and Miscellaneous groups had learning style preferences that more closely mirrored each other on the final survey as compared to the Science group. However, with no apparent significant statistical correlation between groups in reference to learning style preferences or course success, our study aligns with other authors who argue that learning style preferences do not predict course performance (Farkas et al. 2016; Gravenhorst 2007; Hsieh et al. 2012; Husmann and O’Loughlin 2018; Quinn et al. 2017).

Breckler et al. (2009) stated that, although limited in scope and reliability, knowledge of student learning preferences is important for reasons of pedagogy. Quinn and coworkers (2017) argued that an understanding of students’ preferred learning styles can guide course design but it should not be implemented in isolation and can be strengthened (or weakened) by concurrent use of other tools. Assessment of student learning style preferences may be useful in aiding instructors to develop their courses in a way that best engages the diversity of learning styles likely held by their students.

**Study Techniques**

Goldman and Hudson (1973) found that undergraduates majoring in the sciences used different study strategies compared to non-science majors, an observation that agrees with the results of this study. Nearly a quarter of students in the Kinesiology and Miscellaneous groups indicated that they ultimately employed different study techniques in this A&P I course than they had initially predicted. In contrast, Edmunds and Richardson (2009) found no variation in the study habits of undergraduates. They suggested that study habits are more strongly related to the student’s overall conceptions of learning than to the contextual clues of the subject matter.

As noted, students within the Science group were more likely to maintain the same study techniques compared to students in the Kinesiology and Miscellaneous groups. Literature suggests a negative correlation between changing study habits between courses and final anatomy grade (Husmann et al. 2015). Similarly, Ward and Walker (2008) found that students who used a consistent approach to studying achieved higher grades than those who attempted to change. This may indicate that students who understand their own learning style preferences can organize course information into the style that they most prefer (Dobson 2009). In a study examining the relationship between learning style awareness and academic achievement in community college students, there was a significant difference in academic achievement in favor of those aware of their predominant learning style (Cook 1991).

An exception to this may be transitioning from unimodal to multimodal learning. Hu and colleagues, in their 2017 study of learning style preferences and academic performance in first year medical school students, found that doing so allowed students who were struggling to improve their academic performance. This study, along with several others, suggests that multimodal preferences are most common among science and pre-health professions students (Breckler et al. 2009; Goldman and Hudson 1973; Husmann et al. 2015). The number of such students in our study reporting multimodal learning preferences nearly doubled from the initial to the final survey.

Interestingly, Husmann and colleagues (2015) found that most students did not report study strategies that were consistent with their VARK assessment nor did their performance correlate with their VARK score in any category. Students also did not use VARK to make changes to their study strategies. Even those students who did use study strategies consistent with their VARK dominant category had no greater success in the course.

Though students in the Science group were more likely to maintain the same study techniques (a predictor of success according to the literature cited above), they were statistically no more likely to achieve success in this course than students in the Kinesiology and Miscellaneous groups. Similarly, although the number of students indicating multimodal learning style preferences nearly doubled among the Science and Miscellaneous groups (another predictor of success), those groups were again statistically no more likely to achieve

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success in the course. However, it is unclear whether or not individual students who did maintain consistent study habits or embraced multiple learning styles enjoyed higher grades.

**Study Time**

Our results showing that Science students spent less time studying for A&P I than they predicted could indicate that students in the Science group, many of whom were likely enrolled concurrently in other demanding science courses such as organic chemistry, may not have had the time to dedicate to A&P I that they thought they would. On the other hand, Knight and Smith (2010) suggested that previous coursework in the sciences may have led to those in the Science group to develop a better mental framework, encouraging the use of deeper learning. They further proposed that both study habit differences (time and strategy) may reflect different attitudes towards the class. However, at our institution, students in the Science group are actually less likely to have previous A&P coursework at the college level compared to their counterparts in the Kinesiology and Miscellaneous groups.

Other studies predicted that study time along with career goals, not learning preferences, are associated with better performance among a diverse group of students in undergraduate A&P (Breckler et al. 2009; Farkas et al. 2016). For instance, pre-medical students may be more highly motivated as they are seeking admission to competitive programs. Nearly double the percentage of students in the Science group to develop a better mental framework, encouraging the use of deeper learning. They further proposed that both study habit differences (time and strategy) may reflect different attitudes towards the class. However, at our institution, students in the Science group are actually less likely to have previous A&P coursework at the college level compared to their counterparts in the Kinesiology and Miscellaneous groups.

Sturges and coauthors (2016) explored the relationship between student motivation, grade expectation, and academic performance in combined human A&P classes. They found that students were more likely to be extrinsically motivated, indicating a strong preference for rewards or avoidance of punishment and guilt as main drivers to succeed. Their results indicated that students with higher GPAs, who studied for longer periods of time and self-reported to be more motivated to succeed, did better academically in this class.

One may predict an increased likelihood of academic success for students in our Science group based on a review of the existing literature. The Science group had a greater percentage of multimodal learners (Goldman and Hudson 1973; Hu et al. 2017), were less likely to change study habits (Cook 1991; Husmann et al. 2015; Ward and Walker 2008), may have been more highly motivated given their career choice (Breckler et al. 2009; Farkas et al. 2016), and were perhaps more prepared given previous or concurrent coursework in the sciences (Knight and Smith 2010). However, the percentage of students withdrawing from the course or receiving a grade of D or F was not statistically different between the Kinesiology, Science, or Miscellaneous groups.

**Perceived Difficulty of the Course**

In terms of perceived difficulty, the most common response on both the initial and final surveys among all academic groups was 8/10 and the majority of students stated on the final survey that they felt the class was harder than they thought it would be. A 2007 study by Michael sought to better understand this difficulty by asking faculty for their perceptions of why students struggle to learn physiology. Sturges and Maurer (2013) investigated allied health students’ perceptions of what makes the combined undergraduate human A&P class so difficult. Their findings addressed the issue of student ownership as it was evident that students acknowledged their contribution to making this class difficult, even more so than the responsibility they placed on their instructors.

A 2019 study by Slominski and coworkers replicated these studies by collecting survey responses from 466 students at 4 different institutions and from 17 instructors at 15 different institutions. Students in their study attributed the difficulty of human A&P to the nature of the discipline, as opposed to the way physiology was taught or the way students approached learning it. Faculty, like those in the original study by Michael, attributed physiology’s difficulty to factors inherent to the discipline itself. Despite recognizing A&P to be a difficult course, Sturges et al. noted that almost 66% of students in their 2016 study overestimated their final grade, with 29% overestimating it by two to four letter grades.

**Student Success Rates**

We did not find a statistical correlation with success in our A&P I course related to academic group. This differs from Gwazdauskas et al. (2014) who found that biology majors (part of our Science group) did better than other majors. More strongly correlated with success in our A&P I course was class standing with freshmen and sophomores accounting for nearly 81% of all D’s, F’s and withdrawals from the course.

As noted in previous studies, freshman- and sophomore-level students often have a more novice-like approach to learning new material, relying on extensive memorization and using less effective and/or alternative reasoning pathways in response to contextual surface features (Chi et al. 1981; Slominski et al. 2019). These tendencies, along with limited experience learning in undergraduate science classrooms, could lead a student to attribute physiology’s difficulty to teaching practices or studying approaches, as opposed to the discipline itself (Slominski et al. 2019). While it is not possible to identify the specific factors responsible for the higher DWF rate of freshman students in our study, the factors responsible for lower scores in other studies may be involved with our group as well.
Conclusion
There appeared to be no statistical difference in the successful completion of this human anatomy and physiology course between academic groups. Learning style preferences did not appear to vary between the groupings by major although the Science group was more likely to have multimodal learners. The Science group was also more likely than the Kinesiology or Miscellaneous groups to maintain consistent study habits but did not devote as much study time to A&P I as they had predicted compared to the other academic groups. One interesting note is that there were significantly fewer students in the Science group compared to the other two groups who reported taking a previous A&P course at the college level. We do not know if the students in the Kinesiology and Miscellaneous groups, who did report taking a prior college-level A&P course, were repeating the same course or had taken another course. However, this prior course may have been advantageous for some students in these two groups and increased their successful completion of the course.

All academic groups perceived this A&P I course to be equally difficult. One may think that career choice could lead to greater motivation to succeed in A&P among those seeking admission to programs such as medicine or dentistry, of which the Science group contained a greater percentage. Class standing did correlate with student success in this A&P I course; however, students were not surveyed about their career choices, perceptions of learning style preferences, or study habits based on their class standing so it was not possible for us to make any conclusions regarding this data. Investigations into student perceptions with regard to class standing may be worthy of further investigation given its potential impact on program design.

About the Authors
Dr. Karen Keller is an Associate Professor in the Department of Biology at Frostburg State University in Maryland. She teaches undergraduate human anatomy and physiology and a combination of undergraduate and graduate level comparative anatomy, histology, and parasitology courses. She also advises students interested in pursuing careers in various health professions.

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References


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APPENDIX: Initial and Final Surveys Human Anatomy and Physiology

Research Study Initial Questionnaire

We are interested in learning your initial perceptions about the Human Anatomy and Physiology class and how your study habits and attitudes towards studying in general will influence your approach to studying for the course. With this in mind, we are asking you to complete the following questionnaire. Your participation is voluntary and will have no influence on class grades as all responses will be anonymous and class information will be kept confidential. If you choose to participate, please answer all of the following questions honestly. Do not put your name anywhere on this survey. If you have any questions about this questionnaire, please ask your instructor.

Instructions for Descriptive Questions: Please put an “X” by the correct option for each question.

1. What is your current academic major?
   ______ Athletic Training
   ______ Biology
   ______ Chemistry
   ______ Exercise and Sport Science
   ______ Health Science
   ______ Transfer for Health Profession (Pre-Dental Hygiene; Pre-Nursing; Pre-Occupational Therapy)
   ______ Other

2. What is your ultimate career goal?
   ______ Athletic Trainer
   ______ Health Profession at the Bachelor’s (B.S. or B.A.) level (i.e. B.S. in Dental Hygiene, B.S. in Nursing, etc.)
   ______ Health Profession at the Master’s level (i.e. Occupational Therapist, Physician’s Assistant, etc.)
   ______ Health Profession at the Doctorate level (i.e. Chiropractor, Doctor of Osteopathic Medicine, Medical Doctor, Nurse Practitioner, Optometrist, Pharmacist, Physical Therapist, Veterinarian, etc.)
   ______ Personal Trainer
   ______ Research or Academic position that requires a Master’s level degree (M.S.)
   ______ Research or Academic position that requires a Doctorate’s level degree (Ph.D.)
   ______ Other

3. Have you taken a previous Anatomy and Physiology course at the college level?
   ______ Yes
   ______ No
Instructions for Preference Questions: Please answer the questions as honestly as you can and choose the most appropriate answer to each question. Do not spend a long time on each question as your first reaction is probably your best answer. Please put an “X” by the best answer for each question.

1. Which method of learning do you think best describes your learning style?
   _____ Visual/Verbal Learner - Learn best by reading written material, such as a textbook or notes, and looking at diagrams, illustrations, and visual multimedia presentations
   _____ Visual/Nonverbal Learner - Learn best by looking at diagrams, illustrations, and visual multimedia presentations without text
   _____ Auditory/Verbal Learner - Learn best by listening to lectures or presentations and discussing material with a group as well as reading text
   _____ Tactile/Kinesthetic Learner - Learn best by physically manipulating three-dimensional items, such as models or specimens

2. At this point, do you plan to use the same study techniques that you have used for other college classes for the Human Anatomy and Physiology class?
   _____ Yes
   _____ No

3. Compared to other college course that you have already taken, how much time do you plan to study for the Human Anatomy and Physiology course?
   _____ More than other courses
   _____ Same as other courses
   _____ Less than other courses

4. On a scale of 1-10, with 1 being very easy and 10 being the most difficult, how difficult do you think this Human Anatomy and Physiology class will be? (Circle the correct number below.)

   1 2 3 4 5 6 7 8 9 10

Thank you for your participation!

Drs. Keller and Hughes
Does a Student's Academic Major Influence Their Perceptions of a Human Anatomy and Physiology Course and Ultimately Their Success in the Course?

Human Anatomy and Physiology Research Study Final Questionnaire

Now that you have almost completed the Human Anatomy and Physiology class, we are interested in learning whether your initial perceptions regarding your approach to studying for the course have changed. We are asking you to complete a final questionnaire. As before, your participation is voluntary and will have no influence on class grades as all responses will be anonymous and class information will be kept confidential. If you choose to participate, please answer all of the following questions honestly. Do not put your name anywhere on this survey. If you have any questions about this questionnaire, please ask your instructor.

Instructions for Descriptive Questions: Please put an “X” by the correct option for each question.

1. What is your current academic major? (If you changed your major during the semester, please put an “X” on the first line in addition to an “X” by your current major.)
   - [ ] Changed major during the semester
   - [ ] Athletic Training
   - [ ] Biology
   - [ ] Chemistry
   - [ ] Exercise and Sport Science
   - [ ] Health Science
   - [ ] Transfer for Health Profession (Pre-Dental Hygiene; Pre-Nursing; Pre-Occupational Therapy)
   - [ ] Other

2. What is your ultimate career goal? (If your career goal changed during the semester, please put an “X” on the first line in addition to an “X” by your current career goal.)
   - [ ] Changed career goal during the semester
   - [ ] Athletic Trainer
   - [ ] Health Profession at the Bachelor’s (B.S. or B.A.) level (i.e. B.S. in Dental Hygiene, B.S. in Nursing, etc.)
   - [ ] Health Profession at the Master’s level (i.e. Occupational Therapist, Physician’s Assistant, etc.)
   - [ ] Health Profession at the Doctorate level (i.e. Chiropractor, Doctor of Osteopathic Medicine, Medical Doctor, Nurse Practitioner, Optometrist, Pharmacist, Physical Therapist, Veterinarian, etc.)
   - [ ] Personal Trainer
   - [ ] Research or Academic position that requires a Master’s level degree (M.S.)
   - [ ] Research or Academic position that requires a Doctorate’s level degree (Ph.D.)
   - [ ] Other

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Does a Student’s Academic Major Influence Their Perceptions of a Human Anatomy and Physiology Course and Ultimately Their Success in the Course?

Instructions for Preference Questions: As before, please answer the questions as honestly as you can and choose the most appropriate answer to each question. Do not spend a long time on each question as your first reaction is probably your best answer. Please put an “X” by the best answer for each question.

1. Which method of learning do you think best describes your learning style? (If you now think that your learning style is different from what you initially selected, put an “X” on the first line in addition to your current choice.)

_____ I believe I have a different learning style than I selected on the initial questionnaire
_____ Visual/Verbal Learner - Learn best by reading written material, such as a textbook or notes, and looking at diagrams, illustrations, and visual multimedia presentations
_____ Visual/Nonverbal Learner - Learn best by looking at diagrams, illustrations, and visual multimedia presentations without text
_____ Auditory/Verbal Learner - Learn best by listening to lectures or presentations and discussing material with a group as well as reading text
_____ Tactile/Kinesthetic Learner - Learn best by physically manipulating three-dimensional items, such as models or specimens

2. Did you ultimately use the same study techniques that you used for other college classes for the Human Anatomy and Physiology class?

_____ Yes
_____ No

3. Compared to other college courses that you have already completed, how much time did you actually study for the Human Anatomy and Physiology course?

_____ More than other courses
_____ Same as other courses
_____ Less than other courses

4. On a scale of 1-10, with 1 being very easy and 10 being the most difficult, how difficult was this Human Anatomy and Physiology class? (Circle the correct number below.) (If you have changed your opinion on this question, put an “X” on the first line in addition to circling your current choice. Also, indicate whether the class was easier than you thought it would be or harder than you thought it would be.)

1 2 3 4 5 6 7 8 9 10

_____ I have changed my opinion on this question
_____ The class was easier than I thought it would be
_____ The class was harder than I thought it would be

Thank you for your participation!

Drs. Keller and Hughes
Examining the Impact of Case Studies on Student Learning, Interest, Motivation, and Belonging in Undergraduate Human Physiology

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Abstract
Human physiology is a foundational course for future health practitioners. Previous research suggests case studies may improve students' critical thinking and comprehension, but little is known about how case studies affect student interest, motivation, and belonging. The current quasi-experiment investigates the impact of integrating case studies into an otherwise lecture-based human physiology course, compared to traditional lecture-based teaching. We hypothesized that case studies would improve all student outcomes, especially for students from underrepresented groups. Results showed that students in the case study section received higher overall grades and scores for related questions on three exams, combined higher level Bloom's questions on those exams, interest, motivation, and belonging to the course when compared to at least one, and in most cases both, of the comparison sections. We found few significant interactions between course section and student demographic groups, though improvements in final grades appear to be driven by improved grades for women. https://doi.org/10.21692/haps.2021.023

Key words: case studies, human physiology, active learning

Introduction
Lower division human physiology courses are an important gateway to careers in the health science field as they help prepare students for upper division classes and taking health profession entry exams (Cliff and Wright 1996; Smee and Cooke 2018). In these courses, students learn a broad range of content, including interactions spanning almost every system in the body. However, students must also be able to apply their knowledge and draw connections amongst concepts (Cliff and Wright 1996; Ediger 2017; Smee and Cooke 2018). The ability to apply knowledge and draw connections amongst concepts requires higher levels of thinking. The large volume of content covered in the course can conflict with other important learning objectives, especially those involving higher-level thinking skills that ask students to apply their knowledge to medically-related examples. Smee and Cooke (2018) believed students were too focused on remembering facts rather than understanding them and applying them.

Improving teaching in human physiology courses can help students from a broad range of backgrounds and racial and ethnic identities be successful. Improving learning and success for all students is critical for diversifying the future healthcare workforce. More diverse teams are widely recognized as being more successful on a range of metrics (Cheruvelli et al. 2014). Better enabling the success of all students, especially those from minoritized groups, may have direct benefits for those receiving care as patients may be more responsive to healthcare workers with a similar background or identity. For example, a study conducted by Alsan et al. (2018) found that Black men were more likely to undergo preventative health care screenings and services if their doctor was also Black. However, according to the Association of American Medical Colleges, in 2018 only 5% of active physicians identified as Black or African American (AAMC 2018). Unfortunately, lower-level university science, technology, engineering and mathematics (STEM) courses generally have achievement or opportunity gaps in which students from underrepresented and lower socio-economic status backgrounds receive lower grades and have a higher probability of failing (Theobald et al. 2020). More specifically, according to student success statistics provided by the university at which our study was conducted, there is a 14.5% achievement gap in final grades between underrepresented minority (URM) students and non-underrepresented minority (non URM) students taking the introductory human physiology course. Additionally, there is a 7.5% achievement gap in final grades between first generation (first gen) students and non-first generation (non-first gen) students taking the course.

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Integrating case studies into the teaching of human physiology may be a promising start to improving student learning (Birk et al. 2019; Cliff and Wright 1996; Smee and Cooke 2018). Case studies are student-centered activities that contextualize concepts by giving students realistic practical problems to solve while using higher level thinking (Allchin 2013; Herreid 1994; Herreid 1997). Case studies have three key components; an engaging narrative containing contextualized information, questions targeting learning objectives, and class discussion of students’ solutions. (Cliff and Wright 1996; Herreid 1994; Tomey 2003; Wilcox 1999). Cliff and Wright (1996) found that the use of case studies increased student test scores in human physiology lecture classes. Researchers believe this improvement in learning is due to the fact that case studies contextualize information making it easier to visualize and more relatable to the learner and by reinforcing key concepts by focusing on key objectives, (Bonney 2015; Cliff & Wright 1996; Freeman et al. 2014; Herreid 1994; Smee and Cooke 2018). According to Allchin (2013), “contextualizing the learning contributes both to student motivation and to the making of meaning (construed by many educators as central to functional memory and effective learning).”

Case studies may also be useful for decreasing achievement gaps. Case studies almost exactly match the definition of active learning used by Freeman and colleagues (2014) because they emphasize higher order thinking and students learn by participating in activities and discussions in class rather than just listening to lectures. Research has shown that active learning disproportionately benefits underrepresented groups in STEM, possibly because it provides more opportunities to engage with material (Birk et al. 2019; Theobald et al. 2020).

Case studies may simultaneously increase student achievement (Cliff and Wright 1996) and, because it involves active learning, decrease achievement gaps by improving students’ interest and sense of belonging, which are key aspects of student motivation to learn (Theobald et al. 2020). Motivation has been shown to be a key indicator of student performance in a course (Getty et al. 2017). A widely used model of motivation is the expectancy value theory (Eccles 1983), which has recently been expanded to include cost (Getty et al. 2017). Expectancy refers to how well a student expects to do in the course and value refers to how important the course is to a student (Getty et al. 2017; Barron et al. 2017; Eccles 1983). According to Eccles (1983), expectancy and value can have a large effect on student performance. Cost refers to what barriers might prevent a student from succeeding in the course (Getty et al. 2017; Barron et al. 2017).

It is a newer factor to the model, but researchers believe that it is important to take into consideration because it measures factors that may decrease a student’s motivation to learn, and evidence suggests it is a separate construct from value (Getty et al. 2017). Additional psychosocial factors are also important. According to the National Academies of Science, interest and sense of belonging are two of the eight intra- and interpersonal competencies related to achievement in undergraduate education (National Academies of Sciences 2017). Research compiled by the National Academies of Science collectively supplied evidence that a student’s sense of belonging in college is mutable and that a higher sense of belonging is correlated with greater achievement academically (National Academies of Sciences 2017). Additionally, rigorous studies using interventions to increase the relevance students see in the course content differentially benefitted students from underrepresented groups (Canning et al. 2018). Case studies may improve student interest and possibly belonging because the stories spark triggered situational interest where the narrative in the story initially draws the student in, while the group work to complete the problems fosters an ideal situation for maintained situational interest to take hold (Hidi and Renninger 2006). Additionally, contextualization makes the course content relatable and relevant to students. “Real-life” connections may especially help cultivate interest in females and URM students (Allchin 2013).

While case studies hold promise, much remains to be learned about the extent to which this pedagogical approach achieves its aims and the mechanism by which the method may help students achieve these aims. More empirical research is needed to begin to address these claims. Therefore, our research questions are the following:

1. Among students enrolled in a sophomore-level human physiology course, to what extent do learning gains, interest, motivation, and belonging differ between students who have received case study-based instruction and those who have received traditional lecture-based instruction?

2. To what extent do learning gains, interest, motivation, and belonging outcomes vary for students from different demographic groups (first-generation students versus non first-generation students, underrepresented students versus not, and females versus males)?

Methods  
Experimental design

We designed a quasi-experiment using three sections of an undergraduate course in human physiology. One section was taught using case studies (treatment section; Table 1) and two additional sections of the same course, each taught by different instructors, were taught using “business as usual” approaches (comparison sections; Table 1). The curriculum was taught in three five-week blocks, each of which was assessed using an exam (Figure 1). Instructors of the comparison sections primarily used a passive lecture format with heavy reliance on presentation slides. Course content was aligned with the textbook content and the instructors did not use case studies. The instructor of the treatment section mainly used passive lectures that relied on presentation slides but also incorporated three case studies. The complexity and format of the science content was similar in all lecture sections. The
instructors of each section voluntarily agreed to take part in the study. The study was approved by the Institutional Review Board (Protocol #19-236). Students consented to take part in the study without any knowledge of the study’s objectives or hypotheses. To incentivize participation, students received 2% of extra credit at the end of the semester in return for completing two surveys (Figure 1).

Differences between course sections

Due to the quasi-experimental nature of the study, differences between course sections other than those being studied were inevitable (Table 1). Every effort was made to control and address various differences between the course sections. The treatment section was taught by an instructor new to teaching the course in order to mitigate instructor experience from playing a larger role. The treatment and comparison 1 sections were scheduled to be held twice a week for an hour and 50 minutes each while the comparison 2 section was scheduled to meet three times a week for 50 minutes each. However, with the transition to online learning necessitated by the COVID-19 pandemic, all instructors switched to releasing lecture material once a week.

Three exams given throughout the semester made up the bulk of students' final grades in all course sections. Each instructor wrote their own exam, so the total number of questions varied. All three exams were multiple choice with the exception that for exam 1 which was given in a face-to-face setting, one of the comparison instructors included a few free response questions. The only uniform questions on each exam were the researcher developed questions, which were the ones we used to assess student learning (see the data collection instruments section). Other factors included in final grades were short quizzes and homework assignments worth small amounts of points in the comparison sections and case study worksheets in the treatment section. Students in the treatment section were given credit for completing the case studies and participating in the discussion when going over the solutions. Students were not graded on the correctness of their answers.

The treatment section and comparison 1 section both had a learning assistant assigned to their course (Table 1). Learning assistants are undergraduates who serve as supports for the instructors and students during class and who also offer individualized tutoring.

Both comparison instructors gave students a study guide for all exams (Table 1). The study guides contained long lists of topics and learning objectives for students to review as they prepared for exams.

Student population

Student subjects in this study were voluntarily recruited from three sections of a 16-week introductory undergraduate sophomore-level human physiology course at a large, urban, public, Masters-granting Hispanic Serving Institution in California during the spring semester of 2020. A total of 242 students were enrolled in the course during this time; 224 consented to participate in the study (Table 2). Greater than 85% participated and completed all the assessments (Table 2).

<table>
<thead>
<tr>
<th>Treatment Group</th>
<th>Previously taught this course</th>
<th>Used a learning assistant</th>
<th>Gave study guides</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Comparison 1</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Comparison 2</td>
<td>Yes</td>
<td>No</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Table 1. Instructor differences for each human physiology course section

<table>
<thead>
<tr>
<th></th>
<th>Treatment</th>
<th>Comparison 1</th>
<th>Comparison 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Completed Pre-survey</td>
<td>77 (95.1%)</td>
<td>52 (86.7%)</td>
<td>94 (93.1%)</td>
</tr>
<tr>
<td>Completed Exam 1</td>
<td>77 (95.1%)</td>
<td>52 (86.7%)</td>
<td>95 (94.1%)</td>
</tr>
<tr>
<td>Completed Exam 2</td>
<td>77 (95.1%)</td>
<td>51 (85.0%)</td>
<td>95 (94.1%)</td>
</tr>
<tr>
<td>Completed Exam 3</td>
<td>76 (93.8%)</td>
<td>51 (85.0%)</td>
<td>94 (93.1%)</td>
</tr>
<tr>
<td>Completed Post-survey</td>
<td>71 (87.7%)</td>
<td>51 (85.0%)</td>
<td>87 (86.1%)</td>
</tr>
</tbody>
</table>

Note. One student consented to participate but did not fully complete the pre-survey.

Table 2. Percent participation in study at different stages in research

Figure 1. Timeline of the study. The underlined topics on the exams were covered in the treatment section using case studies.
Student demographic data and grades at the end of the semester were obtained from the Registrar’s Office of the university. Of the students included in the study, 149 (66.5%) were female, 74 (33%) were male, and 1 (0.4%) did not supply identification. Eighty students self-identified as an under-represented minority by race or ethnicity (URM) (35.7%), 112 (50%) identified as non-URM and 32 (14.3%) chose not to identify. In addition, 104 students (46.4%) were the first in their family to either attend college or seek a degree (first generation, or first gen), 85 students (37.9%) were non-first generation, and 35 (15.6%) chose to not respond. See table 3 for details on demographic group breakdown by course section.

Case study learning activities

Relevant, freely available case studies from the National Center for Case Study Teaching in Science (NCCSTS; http://sciencecases.lib.buffalo.edu/cs/) were used as active learning activities to support the teaching of skeletal muscle physiology (All or Nothing: A Case study in Muscle Contraction, Neumann et al. 2016), pulmonary physiology (Asthma Attack, Leavitt 2018) and endocrine physiology (Muscleman: A Surprising Case of Shrinkage, Schillo 2012) in the treatment section. The case studies were given after students had reviewed the topic in a lecture format so students could practice applying what they learned. Time devoted to lecture in the case study section was decreased to give students time to complete and review the case study.

The case study on muscle physiology was conducted for ~30 minutes during a face-to-face class meeting. The case study questions were completed in small discussion groups of ~three students. The groups were formed by students partnering up with others sitting near them. The instructor was available to answer questions, but ultimately students were responsible for working through the questions in the case study within their groups. Solutions to the case study questions were delivered using an instructor-facilitated discussion at the end of the class period (Herreid 2005; Murray-Nseula 2011).

On March 19, 2020, the Governor of California issued an Executive Order and Public Health Order that directed all Californians to stay home except to go to an essential job or to shop for essential needs to mitigate the threat of the COVID-19 pandemic. As a result, all university courses switched to an online teaching mode. Due to this unexpected transition to online learning, the case studies on pulmonary and endocrine physiology were completed as asynchronous assignments in the treatment section. The discussion board forum on the course learning management system was used to facilitate student discussion. Students were required to either post a question or answer another student's question on the discussion board to receive full credit for completing the case study assignment. The case study solutions were delivered during a synchronous, instructor-led discussion that occurred via videoconference. Neither the instructor's written solutions, nor the published case study solutions were posted online at any time in accordance with the requirements of the NCCSTS.

Data collection instruments

The pre-survey contained instruments that measured students’ interest (Linnenbrink-Garcia et al. 2010), motivation (Barron et al. 2017), and sense of belonging to the field of health science (Walton et al. 2015). We assessed student content knowledge of muscle, pulmonary, and endocrine physiology using a researcher-developed pre-survey prior to starting the course. The pre-survey contained four questions on skeletal muscle physiology, five questions on pulmonary physiology, and six questions on endocrine physiology. These questions were designed to correlate with the learning objectives for each topic. The post-survey was administered towards the end of the semester, just prior to students taking their final exam. The post-survey contained the same instruments as

<table>
<thead>
<tr>
<th>Demographic Group</th>
<th>Treatment</th>
<th>Comparison 1</th>
<th>Comparison 2</th>
<th>Total</th>
<th>% of dataset</th>
</tr>
</thead>
<tbody>
<tr>
<td>Female</td>
<td>52 (67.5%)</td>
<td>34 (65.4%)</td>
<td>63 (66.3%)</td>
<td>149</td>
<td>66.5%</td>
</tr>
<tr>
<td>Male</td>
<td>25 (32.5%)</td>
<td>18 (34.6%)</td>
<td>31 (32.6%)</td>
<td>74</td>
<td>33.0%</td>
</tr>
<tr>
<td>Sex Not Provided</td>
<td>0 (0.0%)</td>
<td>0 (0.0%)</td>
<td>1 (1.1%)</td>
<td>1</td>
<td>0.5%</td>
</tr>
<tr>
<td>URM</td>
<td>23 (29.9%)</td>
<td>22 (42.3%)</td>
<td>35 (36.8%)</td>
<td>80</td>
<td>35.7%</td>
</tr>
<tr>
<td>Non-URM</td>
<td>42 (54.5%)</td>
<td>24 (46.2%)</td>
<td>46 (48.4%)</td>
<td>112</td>
<td>50.0%</td>
</tr>
<tr>
<td>URM Status Not Provided</td>
<td>12 (15.6%)</td>
<td>6 (11.5%)</td>
<td>14 (14.7%)</td>
<td>32</td>
<td>14.3%</td>
</tr>
<tr>
<td>First Gen</td>
<td>32 (41.6%)</td>
<td>28 (53.8%)</td>
<td>44 (46.3%)</td>
<td>104</td>
<td>46.4%</td>
</tr>
<tr>
<td>Non-First Gen</td>
<td>32 (41.6%)</td>
<td>17 (32.7%)</td>
<td>36 (37.9%)</td>
<td>85</td>
<td>38.0%</td>
</tr>
<tr>
<td>First Gen Status Not Provided</td>
<td>13 (16.9%)</td>
<td>7 (13.5%)</td>
<td>15 (15.8%)</td>
<td>35</td>
<td>15.6%</td>
</tr>
</tbody>
</table>

Table 3. Participation in study by demographic group
the pre-survey minus the content knowledge questions and with additional instruments that measured students’ sense of belonging to the course (Walton et al. 2015) and students’ self-assessment of their learning gains (SALG). The student perception of learning gains instrument was developed using a modified form of the SALG instrument used by Bonney (2015) and researcher-developed questions. The modified SALG instrument used a 5-point Likert scale and included questions 11-16 from Bonney (2015). In addition, an “attending or listening to instructor’s lectures” option was added to each question category. The researcher developed questions asked students to rate, using a 5-point Likert scale, the extent to which they believed they understood each of the three subject areas before and after taking the course. The perception of learning gains score from the researcher-developed instrument was calculated by subtracting student’s self-reported score of what they believed they knew about skeletal muscle, pulmonary, and endocrine physiology at the beginning of the semester, from their self-reported score of how much they believed they learned by the end of the semester. The pre- and post-survey was administered using Qualtrics software (Version Jan., Feb. March, April, May, 2020; Qualtrics; Provo, UT, USA; https://www.qualtrics.com).

We measured student content knowledge after instruction in both treatment and comparison groups using a series of researcher-developed multiple-choice assessments, referred to as midterm content knowledge questions hereafter, that were included on each exam that aligned to specific course learning objectives in all sections. The midterm content knowledge questions were identical across three sections. None of the midterm content knowledge questions were the same as those used on the pre-survey, however, they tested the same concepts. We confirmed that the science concepts on the assessments were presented in each course and students were instructed to review the concepts before each exam. Human physiology and biology instruction experts evaluated the multiple-choice questions to ensure that the items assessed specific Human Anatomy and Physiology Society (HAPS) learning objectives and to categorize each item as either lower Bloom’s learning levels (remember, analyze, evaluate). The HAPS objectives assessed included G0306, G0402, G1301, M0102, M0203, M0301, M0305, M0307, M0602, M0603, M0608, M0614, M0704, M0801, M0901, J0301, J0302, J0401, J0402, J0406, J0501, J0503, J0901.

Instrument reliability

The instrument used to measure interest contained 11 items to measure maintained situational interest using a seven-point Likert scale (7 being strongly agree). According to Linnenbrink-Garcia et al. (2010), the Maintained-SI scale has good internal consistency, with a Cronbach alpha coefficient reported of 0.95 when item 9 and 11 were removed. In the current study, the Cronbach alpha coefficient was 0.94 for the post-survey when all 11 items were included.

The instrument used to measure expectancy, value, and cost contained ten items using a six-point Likert scale (6 being strongly agree). According to Getty et al. (2017) the EVC survey has good internal consistency among the individual components. In the current study, the Cronbach alpha coefficient was 0.88 for expectancy items, 0.82 for value items, and 0.80 for cost items, for the post-survey.

The instrument used to measure belonging to field and course contained five items each, using a seven-point Likert scale and had previously been used by Walton et al. (2015). In the current study, the Cronbach alpha coefficient was 0.79 for the belonging to field scale, and 0.82 for the belonging to course scale, for the post-survey.

Analysis approaches

Statistical analyses were performed using SPSS (IBM Corp. Released 2019. IBM SPSS Statistics for Windows, Version 26.0. Armonk, NY: IBM Corp.). Means are reported ± the standard deviation (SD). For all statistical tests, we used an alpha level of \( p \leq 0.05 \) for rejecting null hypotheses of equivalence of means.

To explore baseline equivalence for pre-survey scores between course sections (treatment, comparison 1, and comparison 2) for student learning gains, interest, motivation, and belonging to the field, we used a one-way between-groups analysis of variance (ANOVA). We conducted a one-way between-groups analysis of covariance (ANCOVA) to compare student learning gains and end of course interest, motivation, and belonging to the field among the three sections. The independent variable was the course section (treatment, comparison 1, and comparison 2), and the dependent variable consisted of the scores on the midterm content knowledge questions and post-survey (Figure 1). Students’ scores on the pre-survey content knowledge questions, interest, motivation, and belonging to the field questions were used as the covariate. Where significant differences were found, we conducted pairwise comparisons to test for differences in the means among each group (treatment, comparison 1, and comparison 2).

Three outcome measures, students’ sense of belonging to the course, students’ perception of their learning gains and final grades only had post-course data. For these measures, we conducted a one-way between-groups analysis of variance (ANOVA) with post hoc comparisons using a Tukey Honestly Significant Difference (HSD) to test for differences in the means among each pairwise comparison.

We conducted a 2 by 2 between-groups analysis of covariance to explore the interaction of underrepresented race/ethnicity status, first generation status, and sex on student learning gains, interest, motivation, belonging to the field, between the treatment and comparison sections. Where significant interactions were found, we conducted a one-way ANCOVA to explore the various simple main
effects. Where significant differences in simple main effects were found, we conducted pairwise comparisons to test for differences in the means among groups.

A two-way between-groups analysis of variance was conducted to explore the impact of URM status, sex, and first gen status on student belonging to the course and final grades in lecture. Where significant interactions were found, we conducted a one-way ANOVA to explore the various simple main effects. Where significant differences in simple main effects were found, we conducted post hoc comparisons using a Tukey HSD to test for differences in the means among each pairwise comparison of groups.

## Results

### Baseline equivalence

There were no significant differences in the pre-survey scores between the treatment and comparison course sections for content knowledge (muscle: $F(2, 220) = 0.18, p = 0.84$, eta squared = 0.002, pulmonary: $F(2, 220) = 0.83, p = 0.44$, eta squared = 0.009, endocrine: $F(2, 220) = 1.37, p = 0.26$, eta squared = 0.01), interest $F(2, 220) = 1.41, p = 0.25$, eta squared = 0.009, motivation (expectancy: $F(2, 220) = 0.26, p = 0.77$, eta squared = 0.001, value: $F(2, 220) = 0.86, p = 0.42$, eta squared = 0.003, cost: $F(2, 220) = 0.12, p = 0.89$, eta squared = 0.001), and belonging to field $F(2, 220) = 0.08, p = 0.93$, eta squared = 0.001 (Table 4).

The effect of using case studies during lecture, regardless of the delivery method (in person or online).

### Student learning

After adjusting for pre-survey content knowledge scores, there was a significant difference between the mean treatment and comparison posttest scores for the content knowledge questions on exam 1: $F(2, 219) = 3.96, p = 0.02$, partial eta squared = 0.04, exam 2: $F(2, 218) = 9.13, p < 0.001$, partial eta squared = 0.08, and exam 3: $F(2, 216) = 48.325, p < 0.001$, partial eta squared = 0.31 (Figure 2). Pairwise comparisons of the adjusted means for exam 1 indicated that the treatment section scored significantly higher than the comparison 2 section ($p = 0.02$). There was not a significant difference between treatment and comparison 1 ($p = 0.14$) or comparison 1 and comparison 2 ($p = 1$) (Figure 2). Pairwise comparisons of the adjusted means for exam 2 indicated that the treatment section scored significantly higher than both comparison 1 ($p < 0.001$) and 2 ($p = 0.02$). There was not a significant difference between comparison 1 and comparison 2 ($p = 0.15$) (Figure 2). Pairwise comparisons of the adjusted means for exam 3 indicated that the treatment section scored significantly higher than both comparison 1 ($p < 0.001$) and 2 ($p < 0.001$). There was also a significant difference between comparison 1 and comparison 2 ($p < 0.001$), with comparison 2 scoring higher (Figure 2).

![Figure 2. Content knowledge scores. Average student score on posttest content knowledge questions after adjustment from pre-survey content knowledge scores. Scores were out of 7, 7, and 8 points for each exam respectively. Error bars represent ±SEM.](image)

<table>
<thead>
<tr>
<th>Measure</th>
<th>Treatment (M±SD)</th>
<th>Comparison 1 (M±SD)</th>
<th>Comparison 2 (M±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Content knowledge</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Skeletal muscle</td>
<td>1.53 (0.9)</td>
<td>1.63 (1.0)</td>
<td>1.55 (1.1)</td>
</tr>
<tr>
<td>Pulmonary</td>
<td>1.84 (1.1)</td>
<td>1.98 (1.2)</td>
<td>1.73 (1.1)</td>
</tr>
<tr>
<td>Endocrine</td>
<td>1.84 (1.2)</td>
<td>1.67 (1.1)</td>
<td>1.56 (1.1)</td>
</tr>
<tr>
<td>Interest</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>63.91 (12.1)</td>
<td>66.87 (9.1)</td>
<td>63.95 (11.1)</td>
<td></td>
</tr>
<tr>
<td>Motivation</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Expectancy</td>
<td>15.00 (2.7)</td>
<td>15.19 (2.3)</td>
<td>14.88 (2.4)</td>
</tr>
<tr>
<td>Value</td>
<td>15.95 (2.0)</td>
<td>15.54 (2.4)</td>
<td>15.54 (2.3)</td>
</tr>
<tr>
<td>Cost</td>
<td>12.43 (3.3)</td>
<td>12.33 (4.2)</td>
<td>12.63 (4.0)</td>
</tr>
<tr>
<td>Belonging to field</td>
<td>25.27 (5.5)</td>
<td>25.42 (5.1)</td>
<td>25.57 (4.8)</td>
</tr>
</tbody>
</table>

Table 4. ANOVA baseline equivalence means and standard deviations

continued on next page
Additionally, after adjusting for pre-survey content knowledge scores, there was a significant difference between the mean treatment, comparison 1, and comparison 2 posttest scores for the higher-level Bloom’s content knowledge questions on all three exams combined $F(2, 219) = 4.78, p = 0.01$, partial eta squared $= 0.04$ with mean scores of 6.26 ($SD=1.9$), 5.25 ($SD=1.9$), and 5.64 ($SD=1.9$), for each section respectively, out of a possible 11 points. Pairwise comparisons of the adjusted means for the higher-level Bloom’s content knowledge questions indicated that the treatment section scored significantly higher than the comparison 1 section ($p = 0.01$). There was not a significant difference between treatment and comparison 2 ($p = 0.10$) or comparison 1 and comparison 2 ($p = 0.73$).

Due to the unexpected transition to online learning caused by the COVID-19 pandemic, the University allowed students to choose a credit/no credit grading option. Students selecting this option were omitted from final grade analysis. One student from comparison 2 was omitted because data was unavailable for administrative reasons. After omitting students who opted for a credit/no credit grade, there was a statistically significant difference in students’ final grade between the treatment and comparison sections $F(2, 212) = 16.87, p < 0.001$, eta squared $= 0.14$ (Figure 3). Post hoc comparisons using the Tukey HSD test indicated that the mean final grades for the treatment section were significantly higher than both comparison 1 ($p < 0.001$) and 2 sections ($p = 0.001$). Comparison sections 1 and 2 mean final grades also differed significantly ($p = 0.04$), with comparison 2 being higher (Figure 3).

**Student interest in the course**

After adjusting for pre-survey scores, there was a significant difference between the mean treatment and comparison post-test interest scores $F(2, 205) = 4.05, p = 0.02$, partial eta squared $= 0.04$ (Figure 4). Pairwise comparisons of the adjusted means for interest indicated that the treatment section scored significantly higher than the comparison 1 section ($p = 0.02$). There was not a statistical difference between treatment and comparison 2 ($p = 0.67$) or comparison 1 and comparison 2 ($p = 0.20$) (Figure 4).

**Student motivation in the course**

After adjusting for pre-survey expectancy, value, and cost scores, there was a significant difference between the mean treatment and comparison post-test scores for expectancy $F(2, 205) = 5.79, p = 0.004$, partial eta squared $= 0.05$ and cost $F(2, 205) = 3.84, p = 0.02$, partial eta squared $= 0.04$. There was no significant difference between treatment and comparison groups for value $F(2, 205) = 1.72, p = 0.18$, partial eta squared $= 0.02$ (Figure 5). Pairwise comparisons of the adjusted means for expectancy indicated that the treatment section scored significantly higher than both the comparison 1 ($p = 0.01$) and comparison 2 sections ($p = 0.02$). There was not a significant difference between comparison 1 and comparison 2 ($p = 1$) (Figure 5). Pairwise comparisons of the adjusted means for cost indicated that the treatment section scored significantly lower

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**Figure 3.** Final grades. Average grades for students enrolled in the study in each of the three undergraduate human physiology sections offered during the spring semester 2020. Grades are reported using the 4-point scale. Error bars represent ±SEM.

**Figure 4.** Interest scores. Average student scores on post-survey interest questions after adjustment from pre-survey interest scores. Scores were out of a possible 77 points. Error bars represent ±SEM.
than comparison 1 ($p = 0.02$). There was not a significant difference between treatment and comparison 2 ($p = 0.33$) or comparison 1 and comparison 2 ($p = 0.48$) (Figure 5).

After adjusting for pre-survey scores, there was not a significant difference between treatment and comparison sections on the post-survey belonging to field score $F(2, 205) = 1.80, p = 0.17$, partial eta squared $= 0.02$ with adjusted mean scores of 26.1 ($SD = 4.3$) for the treatment section, 24.67 ($SD = 4.3$) for comparison 1, and 25.14 ($SD = 4.3$) for comparison 2.

**Student’s assessment of their learning gains**

After calculating a mean gains score for students’ perception of how much they understood each topic at the beginning of the semester versus the end, there was no significant difference between treatment and comparison sections for the muscle topic $F(2, 206) = 0.32, p = 0.72$, eta squared $= 0.003$, the pulmonary topic $F(2, 206) = 0.67, p = 0.52$, eta squared $= 0.01$, or the endocrine topic $F(2, 206) = 1.36, p = 0.26$, eta squared $= 0.01$.

As a part of the modified SALG on the post-survey we asked students which aspects of the class helped their learning and helped them connect scientific concepts to their everyday life. Students in the treatment section believed the case studies helped a moderate to good amount. Additionally, when comparing the three treatment groups, students in the treatment section believed that instructor lectures and class discussions were more helpful (Tables 5 and 6).

### Table 5. Means and standard deviations for the question:

**Overall, how much did each of the following aspects of the class help your learning?**

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment (M±SD)</th>
<th>Comparison 1 (M±SD)</th>
<th>Comparison 2 (M±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attending or listening to instructor’s lectures</td>
<td>5.27 (0.9)</td>
<td>4.63 (1.4)</td>
<td>4.62 (1.2)</td>
</tr>
<tr>
<td>Completing case studies</td>
<td>4.90 (1.1)</td>
<td><em>a</em></td>
<td><em>a</em></td>
</tr>
<tr>
<td>Participating in discussions during class</td>
<td>4.31 (1.5)</td>
<td>3.76 (1.5)</td>
<td>3.23 (2.0)</td>
</tr>
<tr>
<td>Reading the textbook</td>
<td>3.59 (1.6)</td>
<td>3.00 (1.5)</td>
<td>3.95 (1.5)</td>
</tr>
</tbody>
</table>

Note. Likert scale key is as follows: 1-NA, 2-provided no help, 3-helped a small amount, 4-helped a moderate amount, 5-helped a good amount, 6-helped a great amount. Treatment n=71, comparison 1 n=51, and comparison 2 n=87.

*a* Means and SD for this item was excluded since comparison groups did not receive case-based instruction.

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**Figure 5. Motivation scores.** Average student scores on post-survey expectancy, value, and cost questions after adjustment from pre-survey expectancy, value, and cost scores. Scores were out of 18, 18, and 24 points respectively. Error bars represent ±SEM.

**Figure 6. Belonging to course scores.** Average student scores on post-survey belonging to course questions. Scores were out of 35 points. Error bars represent ±SEM.
Analyses of interactions among moderating demographic variables showed that most interactions were not significant. The following results are the few significant interactions and simple main effects we found.

A generation (first vs non first) x treatment groups (treatment, comparison 1, comparison 2) ANCOVA was conducted on exam 1, controlling for pre-survey content knowledge scores. Results found a significant main effect for treatment groups $F(2, 181) = 4.73, p = 0.01$, partial eta squared = 0.05, and no significant main effect for generation status $F(1, 181) = 0.95, p = 0.33$, partial eta squared = 0.01. Results also found a significant interaction $F(2, 181) = 4.17, p = 0.02$, partial eta squared = 0.04.

Simple main effect follow-up analyses for first generation college students found that there was a significant difference between the mean treatment and comparison posttest content knowledge scores for first generation students taking exam 1 $F(2, 100) = 9.57, p < 0.001$, partial eta squared = 0.16 (Table 7). Pairwise comparisons indicated that the treatment section scored significantly higher than both the comparison 1 ($p < 0.001$) and comparison 2 sections ($p = 0.002$). There was no significant difference between comparison 1 and comparison 2 ($p = 0.95$) (Table 7).

For non-first generation college students, no significant differences were found among treatment groups $F(2, 80) = 0.59, p = 0.56$, partial eta squared = 0.02.

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment (M±SD)</th>
<th>Comparison 1 (M±SD)</th>
<th>Comparison 2 (M±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attending or listening to instructor’s lectures</td>
<td>5.15 (1.0)</td>
<td>4.65 (1.4)</td>
<td>4.74 (1.1)</td>
</tr>
<tr>
<td>Completing case studies</td>
<td>5.06 (1.1)</td>
<td><strong>a</strong></td>
<td><strong>a</strong></td>
</tr>
<tr>
<td>Participating in discussions during class</td>
<td>4.35 (1.5)</td>
<td>3.96 (1.5)</td>
<td>3.53 (1.9)</td>
</tr>
<tr>
<td>Reading the textbook</td>
<td>3.45 (1.6)</td>
<td>3.16 (1.6)</td>
<td>3.95 (1.6)</td>
</tr>
</tbody>
</table>

Table 6. Means and standard deviations for the question: Overall, how much did each of the following aspects of the class help you to understand the connections between scientific concepts and other aspects of your everyday life?

Sex, URM, and first-generation status

Analyses of interactions among moderating demographic variables showed that most interactions were not significant. The following results are the few significant interactions and simple main effects we found.

A sex (male vs female) x treatment groups (treatment, comparison 1, comparison 2) ANCOVA was conducted on exam 3, controlling for pre-survey content knowledge scores. Results found a significant main effect for treatment groups $F(2, 212) = 37.2, p < 0.001$, partial eta squared = 0.26, and no significant main effect for sex $F(1, 212) = 1.36, p = 0.25$, partial eta squared = 0.01. Results also found a significant interaction $F(2, 212) = 3.26, p = 0.04$, partial eta squared = 0.03.

Simple main effect follow-up analyses for female college students found that there was a significant difference between the mean treatment and comparison posttest content knowledge scores for female students taking exam 3 $F(2, 143) = 44.93, p < 0.001$, partial eta squared = 0.39 (Table 8). Pairwise comparisons indicated that the treatment section scored significantly higher than both the comparison 1 ($p < 0.001$) and comparison 2 sections ($p < 0.001$). There was also a significant difference between comparison 1 and comparison 2 ($p < 0.001$), with comparison 2 scoring higher (Table 8).

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment (M±SD)</th>
<th>Comparison 1 (M±SD)</th>
<th>Comparison 2 (M±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attending or listening to instructor’s lectures</td>
<td>5.15 (1.0)</td>
<td>4.65 (1.4)</td>
<td>4.74 (1.1)</td>
</tr>
<tr>
<td>Completing case studies</td>
<td>5.06 (1.1)</td>
<td><strong>a</strong></td>
<td><strong>a</strong></td>
</tr>
<tr>
<td>Participating in discussions during class</td>
<td>4.35 (1.5)</td>
<td>3.96 (1.5)</td>
<td>3.53 (1.9)</td>
</tr>
<tr>
<td>Reading the textbook</td>
<td>3.45 (1.6)</td>
<td>3.16 (1.6)</td>
<td>3.95 (1.6)</td>
</tr>
</tbody>
</table>

Table 7. ANCOVA results comparing treatment groups on exam 1 for first generation college students

A sex (male vs female) x treatment groups (treatment, comparison 1, comparison 2) ANCOVA was conducted on exam 3, controlling for pre-survey content knowledge scores. Results found a significant main effect for treatment groups $F(2, 212) = 37.2, p < 0.001$, partial eta squared = 0.26, and no significant main effect for sex $F(1, 212) = 1.36, p = 0.25$, partial eta squared = 0.01. Results also found a significant interaction $F(2, 212) = 3.26, p = 0.04$, partial eta squared = 0.03.

Simple main effect follow-up analyses for female college students found that there was a significant difference between the mean treatment and comparison posttest content knowledge scores for female students taking exam 3 $F(2, 143) = 44.93, p < 0.001$, partial eta squared = 0.39 (Table 8). Pairwise comparisons indicated that the treatment section scored significantly higher than both the comparison 1 ($p < 0.001$) and comparison 2 sections ($p < 0.001$). There was also a significant difference between comparison 1 and comparison 2 ($p < 0.001$), with comparison 2 scoring higher (Table 8).

<table>
<thead>
<tr>
<th>Item</th>
<th>Treatment (M±SD)</th>
<th>Comparison 1 (M±SD)</th>
<th>Comparison 2 (M±SD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Attending or listening to instructor’s lectures</td>
<td>5.15 (1.0)</td>
<td>4.65 (1.4)</td>
<td>4.74 (1.1)</td>
</tr>
<tr>
<td>Completing case studies</td>
<td>5.06 (1.1)</td>
<td><strong>a</strong></td>
<td><strong>a</strong></td>
</tr>
<tr>
<td>Participating in discussions during class</td>
<td>4.35 (1.5)</td>
<td>3.96 (1.5)</td>
<td>3.53 (1.9)</td>
</tr>
<tr>
<td>Reading the textbook</td>
<td>3.45 (1.6)</td>
<td>3.16 (1.6)</td>
<td>3.95 (1.6)</td>
</tr>
</tbody>
</table>

Table 8. ANCOVA results comparing treatment groups on exam 3 for female students
Examining the Impact of Case Studies on Student Learning, Interest, Motivation, and Belonging in Undergraduate Human Physiology

For male students taking exam 3, simple main effect follow up analyses found that there was a significant difference between the mean treatment and comparison posttest content knowledge scores $F(2, 68) = 8.24, p = 0.001$, partial eta squared $= 0.20$ (Table 9). Pairwise comparisons indicated that the treatment section scored significantly higher than the comparison 1 section ($p < 0.001$), but not the comparison 2 section ($p = 0.28$). There was also a significant difference between comparison 1 and comparison 2 ($p = 0.03$), with comparison 2 scoring higher (Table 9).

<table>
<thead>
<tr>
<th>Treatment Groups</th>
<th>Adjusted Mean</th>
<th>SD</th>
<th>n</th>
<th>F</th>
<th>partial $\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>5.83 a</td>
<td>1.2</td>
<td>25</td>
<td>8.24*</td>
<td>0.2</td>
</tr>
<tr>
<td>Comparison 1</td>
<td>4.24 b</td>
<td>1.2</td>
<td>17</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison 2</td>
<td>5.24 a</td>
<td>1.3</td>
<td>30</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *$p < 0.05$. Score for exam 3 was out of 8.

Means with different letters next to them denote significant differences.

Table 9. ANCOVA results comparing treatment groups on exam 3 for male students

For male college students, no significant differences were found among treatment groups $F(2, 68) = 0.94, p = 0.40$, eta squared $= 0.03$.

<table>
<thead>
<tr>
<th>Treatment Groups</th>
<th>Mean</th>
<th>SD</th>
<th>n</th>
<th>F</th>
<th>$\eta^2$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Treatment</td>
<td>3.78 a</td>
<td>0.5</td>
<td>50</td>
<td>3.30*</td>
<td>0.22</td>
</tr>
<tr>
<td>Comparison 1</td>
<td>2.76 b</td>
<td>1.1</td>
<td>33</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Comparison 2</td>
<td>3.22 c</td>
<td>0.7</td>
<td>61</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Note. *$p < 0.001$. Grades are reported using the 4-point scale.

Means with different letters next to them denote significant differences.

Table 10. ANOVA results comparing treatment groups on final grades for female students

Discussion

The purpose of this quasi-experiment was to test the hypothesis that integrating case studies into an introductory human physiology course would increase students’ learning gains, interest, motivation, and sense of belonging compared to the two comparison sections that did not use case studies.

Exploring outcomes in student learning

Our results show that on all three exams, the treatment group scored significantly higher on the post-survey content knowledge questions than one or in some cases both of the comparison sections. Exam 1 was the only exam given in an in-person classroom setting, and was the only exam in which the treatment section scored significantly higher than only one of the comparison sections, comparison 2. While not significant, the difference in means between the treatment and comparison 1 section was nearly the same as the difference in means between the treatment and comparison 2, but the smaller sample size in comparison 1 led to lower statistical power. Exams 2 and 3 were given online after the switch to virtual learning caused by the COVID-19 pandemic, and in both cases the treatment section scored significantly higher than both of the comparison sections. Exam 3 which covered the endocrine system had the largest difference with the treatment section scoring 58% higher than comparison 1 and 22% higher than comparison 2. Our results are similar to the findings of Cliff and Wright (1996) who found that the addition of case studies to the anatomy and physiology course resulted in an increase in exam scores and the general findings for positive impacts of active learning (Freeman et al. 2014). The general increase in improvement of the scores of students learning with case studies may be explained by differences in the cases themselves, the benefits of continued practice
with case studies, or that conducting case studies online may be more beneficial. Future studies that explore the impact of case study dosage would be valuable, as would studies that rigorously explore using case studies in online versus face-to-face settings.

Case studies have been hypothesized to increase students’ ability to think critically, improving problem solving skills and depth of learning (Allchin 2013; Cliff and Wright 1996; Herreid 1994; Herreid 2004; Murray-Nseula 2011; Smee and Cooke 2018; Tomey 2003; Willcox 1999; Yadav et al. 2007). When our post-survey content knowledge questions on the exams were separated by Blooms level and analyzed, we found that the treatment section scored significantly higher than the comparison 1 section for the higher-level Blooms questions. This is significant because students being able to answer higher level Blooms questions conveys a deeper understanding of the content and ability to think critically which is important for students in the health science field.

Our results also show that students in the treatment section received significantly higher final grades than both comparison sections which has important implications for student persistence in the health science professions and for possibly decreasing failure or repeat rates. These results are compelling and are suggestive that some factor in the treatment section, namely the use of case studies, has led to the higher overall performance of the treatment section compared to the comparison sections, though the quasi-experimental design of the study does not allow us to reject alternative explanations for these differences. The results of analyses of data disaggregated by demographic groups suggest that the improvement in grades for the case studies class was driven primarily by increases in the success of students who identify as women. We encourage additional replications of this type of research on case studies to see if this result applies more generally.

The unique situation created by the response to COVID-19 where all learning was transitioned to an online format midsemester is not lost on us. The continued out-performance of the treatment group compared to the comparison groups despite the transition midsemester may suggest that case studies are effective for use in both in-person and online learning formats.

Exploring outcomes in student interest

Student interest in physiology is an important outcome in and of itself and may significantly affect other academic outcomes such as achievement (National Academies of Sciences 2017). Our results demonstrate that the treatment section had higher levels of interest than our comparison 1 section. Though our treatment section scored higher on interest than our comparison 2 section, the difference was not statistically significant. Effect sizes were small to medium. It is interesting to note that the comparison 1 section had lower final grades when compared to the treatment and comparison 2 section. It may be possible that this low level of interest expressed in the comparison 2 section contributed negatively to final grades in the course while the higher level of interest in the treatment section contributed positively to overall grades in the course. We cannot be sure that the case studies in the treatment section are responsible for the higher level of interest expressed.

Exploring outcomes in student motivation

The instrument we used for a motivation construct includes three factors that contribute to motivation: expectancy, value, and cost. Creators of the measure highlighted its usefulness for measuring the effects interventions may have on student motivation and its ability to predict how these three factors affect student achievement and interest (Getty et al. 2017). Although students in all three courses started with similar levels of expectancy, value, and cost, our results demonstrate that students in the treatment section had higher levels of expectancy at the end of the course, compared to our comparison sections. Students in the treatment section also had lower levels of cost compared to the comparison 1 section, meaning that students in the treatment section reported fewer barriers to being successful in the course, such as time and effort. Again, though our treatment section had lower levels of cost than our comparison 2 section, the difference was not statistically significant. There was no difference between treatment groups for value. This finding was surprising to us and requires further investigation.

Exploring outcomes in student sense of belonging

The National Academies of Science have identified belonging as an important core competency related to student achievement and indicated that its development may be most beneficial for students from underrepresented groups (National Academies of Sciences 2017). We used two different measures to evaluate student sense of belonging. The first measure asked about students’ sense of belonging to the health science field. Baseline equivalency was established amongst all three sections for this measure. Our results showed that there was no difference among treatment groups for students’ sense of belonging to the field at the end of the course. Student sense of belonging actually remained relatively unchanged from the beginning of the semester to the end across all three treatment groups. This was somewhat surprising to us since we had hypothesized that the case studies in the treatment group would increase students’ sense of belonging to the field, yet in other respects it was not too surprising because only three case studies were used in this quasi-experiment.

The second measure we used asked about students’ sense of belonging in the course itself which was only included on the post-survey. Our results showed that students in the treatment section felt as though they belonged to the course significantly more than the comparison sections with moderate effect sizes. We suspect that the use of case studies and the format of students working together on them may have contributed to the increased sense of belonging in the
treatment section. With the transition to online learning mid semester, this result of increased belonging in the treatment section is particularly noteworthy and again speaks to the value of using case studies.

Exploring outcomes in student assessment of learning gains
A measure was included on the post-survey asking students about how much they perceived they learned about each of the researched systems (skeletal muscle, pulmonary, and endocrine). There was no difference found between treatment groups. These results are somewhat similar to those from a study by Deslauriers et al. (2019), which found that students in active learning classes in physics feel like they learned less than their peers in passive learning classes even though they actually learned more.

When asked how well they felt the case studies helped with their learning and ability to make connections between what they learned and their everyday life, students in the treatment section, on average, believed the case studies helped “a good amount”. This is similar to what Bonney (2015) found using a similar modified SALG instrument. Wilcox (1999) gave students a Likert scale survey asking students about the usefulness of case studies in the course in which most students responded that they found the case studies “useful”.

Exploring outcomes for disaggregated demographic groups
When comparing outcomes for various demographic groups (male, female, URM, non-URM, first gen, and non-first gen), our results demonstrated that very few differences were found between treatment groups. When differences were found, they tended to favor underrepresented groups in the treatment section. The most notable difference was found in the results of final grades for females described earlier. Other differences found include first generation students in the treatment section scoring significantly higher than comparison sections on the content knowledge questions for exam 1, and female students in the treatment section scoring significantly higher than comparison section for the content knowledge questions on exam 3.

Conclusion
Using case studies to help teach human physiology is a worthwhile endeavor. Students generally feel like they are helpful and the use of just three case studies throughout a semester resulted in positive marked differences in exam scores, final grades, ability to learn and understand concepts, interest, expectancy to succeed, lower costs, and an improved sense of belonging to the course which may be attributed to the case studies. Further studies using more rigorous experimental designs are warranted to further analyze the impact of case studies on student learning and motivation.

Limitations
As any study that involves human subjects, our study does have several limitations. One factor that may explain the differences we observed are instructor related. As a quasi-experiment, we did not control for differences in instructor experience, personality, or even teaching style which is why we called our non-treatment groups our “comparison” groups rather than “control” groups. Additionally, with only one treatment section it is possible that an instructor-related variable outside the use of case studies could explain the differences observed between sections. We were limited to only having three sections of the course available for analysis and chose to implement case studies in one because it better enabled us to explore possible confounding factors that were distributed among the two comparison groups. For example, class size varied among the three sections (from 60-101 students). However, the influence of class size on student achievement is questionable for courses larger than 30 (Ake-Little 2020) and the treatment section class size was intermediate between the two comparison sections. Other possible confounding factors that we were able to consider included the use of learning assistants by both the treatment and comparison 1 sections, and the number of times a week a class was held prior to moving online. This study attempted to balance instructor differences by assigning the least experienced instructor to teach the treatment section.

A general critique of quasi-experiments is that student enrollment in different sections is not random. To help address this concern, we conducted baseline comparisons. All three course sections showed baseline equivalence for pre-survey content knowledge, interest, motivation, and belonging to the field. This means that each section can be assumed to have started the course at the same level of understanding, interest, motivation, and belonging, increasing the likelihood that we can attribute changes in outcome variables to differences in pedagogy.

Another limitation to the study is student attendance. Due to the large class size in each course section, attendance was not taken and it is quite possible that student absences may have contributed negatively towards grades. This problem may have been more significant if students missed the day the case studies were completed in class or did not complete the assignment at all.

Mid semester, the COVID-19 pandemic necessitated a transition to online learning. In many ways the transition to online teaching made the classes more equivalent. Prior to the transition to online learning, one of the comparison sections was scheduled to hold class three days a week while the other comparison section and the treatment section were scheduled to hold class twice a week. With the transition to online learning, all instructors delivered their course content in the same manner, asynchronously once a week. The transition to online learning warrants future work. In this study, one case study was implemented before the transition and the results for the impact of the case study on student achievement were consistent (though the differences in means were slightly lower) with results from case studies conducted after the transition to virtual teaching. However, because of the difference in the way the first case study was conducted (in

continued on next page
person), versus the second and third case studies (online), care must be taken when comparing the results to each other. For example, exam 1 was proctored in person, meaning that there were fewer opportunities for students to cheat compared to the online format for exams 2 and 3. While there is no evidence of significant cheating on exams, the possibility remains. The transition to remote learning during this semester also brought with it profound psychological effects due to fear, mandates on social distancing, and inadequate home learning environments to name a few. The transition to remote learning compounded with these psychological effects may have had an impact on students’ interest, motivation and sense of belonging.

Acknowledgments

We thank the lecturers for allowing us to conduct research in their courses. Without their unwavering support, especially in light of having to transition to online learning, this study would not have been possible. We would also like to thank the CPP Registrar Office for providing us with University data, the many students who participated in the study, and the NCCSTS for providing a valuable platform for case studies.

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References


Examining the Impact of Case Studies on Student Learning, Interest, Motivation, and Belonging in Undergraduate Human Physiology


Use of iLearning in an Introductory Human Anatomy and Physiology Course

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* Corresponding Author

Abstract
The incorporation of mobile learning methods (iLearning) into human anatomy and physiology classrooms has been debated with regard to its effectiveness in higher education. This study aimed to understand how iLearning affects college-aged students' perception of learning and engagement in an introductory human anatomy and physiology course using a survey established by Rossing and coworkers (2012). Perceived learning was not significantly different from start to end of the semester while perceived engagement was significantly different in a negative direction. Mean scores were high for both dimensions at both time points which may have diminished meaningful interpretation. Nevertheless, the present study demonstrates that iLearning can be successfully implemented into higher education classroom settings while maintaining traditional classroom teaching and learning techniques. https://doi.org/10.21692/haps.2021.024

Key words: iLearning, classroom technology, anatomy course design, engagement

Introduction
The intersection of traditional classroom instruction styles with technology is a trend that is projected to continue (Raney 2016; Rossing et al. 2012). Technology has the potential to reach and engage students with varying learning styles, allowing expansion of possibilities in the classroom. Teachers can deliver a more customized education to students through technology (Johnson et al. 2011) and positively influence their academic success (Raney 2016; Rossing et al. 2012). The National Survey of Student Engagement (NSSE) identified technology as a significant and important trend for learning and skill building (BrckaLorenz et al. 2013). Active learning approaches, such as those that engage students in different ways to learn course concepts, presents a new opportunity for course design compared to traditional rote memorization laboratory activities (Griff 2016). Furthermore, the integration of tablets and app-related learning has shown a positive effect on student achievement and attendance (Wilkinson and Barter 2016). The integration of technology in the classroom provides several opportunities in undergraduate coursework.

There are different terms to reference technology and learning in the classroom. Mobile learning has been defined as the use of tablets, mobile devices, or other mobile technologies for learning (Jacob and Issac 2008; Traxler 2013). Similar yet distinctive from mobile learning, iLearning specifically incorporates Apple technology for education. This concept involves an intentional course design component through the use of supplementary technology, rather than serving as a substitute for teaching. For the purposes of this paper, iLearning refers to the use of iPads as the classroom technology intervention mode.

The current generation of students in residential college settings have exceptional intuition with technology; a majority use smartphones daily (Rossing et al., 2012). There is reason to assume students may prefer the use of technology for learning (Kvavik, 2005). Previous research indicates that students have held a positive attitude about using iPads for learning (Brand et al. 2011; Kinash et al. 2012; Perez et al. 2011; Rossing et al. 2012; Wakefield and Smith 2012). In a research study of over 4000 undergraduate students, most (41.2%) preferred classes with a moderate level of technology (Kvavik 2005). Moreover, having a major specific to the life sciences was found to be a predictor for preferring integration of technology into the classroom (Kvavik 2005). Teachers can reach the present generation of students through iLearning as most already have an intuitive mastery of technology.

Some research to date supports iLearning in human anatomy and physiology coursework. In a study of university anatomy courses, Wilkinson and Barter (2016) found tablet usage positively affected knowledge retention, application of knowledge, and/or a deeper understanding of difficult concepts. All assessment scores between traditional and mobile learning teaching strategies favored the use of iPads in the classroom (Wilkinson and Barter 2016). In another study of undergraduate students, Chakraborty and Cooperstein (2017) reported overall grade improvement when iPad apps were incorporated into the course. Moreover, there was a correlation between frequency of iPad use and course grade (Chakraborty and Cooperstein 2017).
There is an opportunity to enhance the classroom environment and student outcomes by intentional integration of iLearning methods. Some evidence to support iLearning in anatomy and physiology coursework is available; however, Griff (2016) and Nguyen et al. (2014) call for more research in course design to best align teaching and learning. The purpose of this study was to determine if iLearning improved perceived learning and perceived engagement in undergraduate students enrolled in an introductory human anatomy and physiology course by addressing the following two research questions:

Does use of iLearning (use of iPads) in an introductory human anatomy and physiology course change student perceived learning outcomes? The researchers hypothesized perceived learning would increase after a semester of using iPads in the classroom.

Does use of iLearning (use of iPads) in an introductory human anatomy and physiology course change student perceived engagement outcomes? The researchers hypothesized perceived engagement would increase after a semester of using iPads in the classroom.

**Methods**

**Institution Approval**

This project was approved by the Central College Institutional Review Board (#H-02-F2018-CH and #H-04-F2019-CH) and informed consent was obtained from all participants.

**Subjects**

All recruited subjects were undergraduate students at a private, liberal arts school in the Midwest. A convenience sample of students enrolled in an introductory human anatomy and physiology course were recruited to participate in the study. Students were told that iLearning (use of iPads) would generally be incorporated into the class design and were asked to complete a survey at the beginning and end of the semester about their views of iLearning in the classroom. Participation was voluntary, anonymous, and had no effect on class evaluation outcomes. There were 92 students enrolled in the course: 51 male and 41 female. In total, 73 students participated in the study. Of those, 53 students (28 male, 24 female, and 1 did not disclose) completed both pre- and post-surveys (72.6% return rate) and were included in the data analyses. All students were between the ages of 18 and 28 years.

**Procedures**

The present study was a quasi-experimental mixed methods design. The use of iPads in an introductory human anatomy and physiology course was initiated in fall 2018. The researchers earned an institutional grant in order to purchase necessary equipment. Students were asked to participate in the study and complete a paper version of the Rossing et al. (2012) iLearning survey prior to the start of the first lab period.

Lecture and laboratory iLearning activities were used to complement traditional teaching in the classroom throughout the semester; examples included use of app images, videos, and quizzes.

iLearning activities typically involved small groups, meaning no more than 3 students to an iPad. Specifically, on handouts in lecture or lab, students were asked to identify structures within the app utilizing different 3-dimensional views, ascertain content from videos to complete sentences or aid in class discussion, or take randomized (but not graded) small group quizzes on the app to reinforce repetition in learning anatomy. It was estimated iLearning accounted for 30 minutes out of a possible 4 hours and 5 minutes per week of in-class activities. During the final lab period students were again asked to complete the iLearning survey.

**Measures**

Quantitative and qualitative data were collected using the iLearning survey created by Rossing et al. (2012; Appendix 1) and permission to use the survey was granted by Jonathan Rossing (Appendix 2). The survey includes 12 Likert-scale questions categorized into 2 dimensions: student perceived learning or student perceived engagement. Additionally, open-ended questions about iLearning were also asked on the survey.

**Quantitative Scoring**

The 12 survey questions were assessed on a Likert scale from strongly agree (5) to strongly disagree (1). Questions 1 through 6 reflected student perceived learning and questions 7 through 12 reflected student perceived engagement.

**Psychometric properties**

No psychometric properties were available for the survey. Additionally, aggregate course grades (percentages) were de-identified and collected by semester. Then, grade averages were compared for the 3 semesters before iLearning implementation in the course and the 3 semesters after the intervention.

**Data Analysis**

All quantitative data were analyzed using Statistical Package for the Social Services (SPSS) version 26 (IBM, Armonk, NY). Student paired t-tests were used to analyze any change to student perception of learning pre-iLearning intervention to post-intervention and any change to student perception of engagement pre-iLearning intervention to post-intervention. Moreover, Student’s paired t-tests were used to further analyze individual questions on the survey to determine specific changes within the dimensions of learning and engagement. An a priori level of .05 was set to determine statistical significance.

A content analysis was performed on the survey open-ended responses using techniques described by Ryan and Bernard (2003). The coding process involved reading the open-ended survey answers; the first time without note taking while the
second time involved highlighting common or repetitive ideas and themes. A comparison method was then used to distinguish opportunities and limitations described by the subjects and these were grouped by identified themes. This qualitative information was then utilized to best make meaning of the quantitative data.

**Results**

There was a significant difference \((p < 0.001)\) in perceived engagement from the beginning \((M = 25.79 \pm 4.67)\) to the end \((M = 22.32 \pm 3.88)\) of the semester. There was no significant change \((p = 0.54)\) in perceived learning from the beginning \((M = 25.19 \pm 3.09)\) to the end \((M = 25.49 \pm 3.66)\) of the semester. Data is summarized in Table 1.

Aggregate course grades were 82.41 ± 11.77% before and 82.97 ± 8.19% after iLearning strategies were implemented.

Five themes were established through qualitative analysis: access and availability, sharing and collaboration, novelty, learning style, and convenience. Students had more positive (opportunities) than negative (limitations) comments for each theme except for convenience. When the comments for iLearning were analyzed based on the perception of convenience, 32 were considered positive reflections of the intervention whereas 33 comments were stated as a negative. Of the comments that viewed iLearning as a positive addition to the course, 61.5% \((n=32)\) noted the iPads and app as effective tools for the content covered and 37.7% \((n = 20)\) stated that the interactive nature of the app increased involvement. The top limitation to iLearning was that the technology could be uncooperative at times (e.g., touch sensitivity, screen freeze), mentioned by 41.5% \((n=22)\) of the sample. A summary of the most common comment for each qualitative theme is shown in Table 3.

### Table 1. iLearning survey results by dimension.

<table>
<thead>
<tr>
<th>Time</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>(p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pre-</td>
<td>25.19</td>
<td>3.09</td>
<td>0.540</td>
</tr>
<tr>
<td>Post-</td>
<td>25.49</td>
<td>3.66</td>
<td>&lt; 0.001</td>
</tr>
<tr>
<td>Pre-</td>
<td>25.79</td>
<td>4.67</td>
<td></td>
</tr>
<tr>
<td>Post-</td>
<td>22.32</td>
<td>3.88</td>
<td></td>
</tr>
</tbody>
</table>

Further analysis showed significant differences for 3 specific questions asked on the survey (Table 2). Regarding the perceived learning dimension, student confidence in course content (question 5) increased \((p = 0.018)\) through the use of the iPad and associated activities. With respect to perceived engagement, questions 8 and 10 showed a significant change \((p = 0.041 and \ p < 0.001, \text{ respectively})\). For question 8, students expressed a reduction \((p = 0.041)\) in their perceived participation in class with the iPad at the beginning of the semester \((M = 3.54 \pm 93)\) compared to the post-data collection \((M = 3.19 \pm 98)\). Responses to question 10 revealed that students found the iPad technology to be more convenient \((p < .001)\) than using a standard computer when surveyed at the end of the semester.

### Table 2. iLearning survey results by question

<table>
<thead>
<tr>
<th>Question</th>
<th>Time</th>
<th>Mean</th>
<th>Std. Deviation</th>
<th>(p)-value</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>Pre-</td>
<td>3.96</td>
<td>.76</td>
<td>0.018*</td>
</tr>
<tr>
<td></td>
<td>Post-</td>
<td>4.25</td>
<td>.71</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>Pre-</td>
<td>3.54</td>
<td>.93</td>
<td>0.041*</td>
</tr>
<tr>
<td></td>
<td>Post-</td>
<td>3.19</td>
<td>.98</td>
<td></td>
</tr>
<tr>
<td>10</td>
<td>Pre-</td>
<td>3.74</td>
<td>.88</td>
<td>&lt;0.001**</td>
</tr>
<tr>
<td></td>
<td>Post-</td>
<td>4.32</td>
<td>.61</td>
<td></td>
</tr>
</tbody>
</table>

*significant at \(p < .05\)

**significant at \(p < .001\)

### Table 3. iLearning themes identified through qualitative analysis.

<table>
<thead>
<tr>
<th>Theme</th>
<th>Comment</th>
<th>Percentage ((n))</th>
<th>Opportunity or Limitation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Access &amp; availability</td>
<td>Effective tool for content</td>
<td>61.5% ((32))</td>
<td>Opportunity</td>
</tr>
<tr>
<td>Convenience</td>
<td>Uncooperative technology</td>
<td>41.5% ((22))</td>
<td>Limitation</td>
</tr>
<tr>
<td>Learning styles</td>
<td>Interactive and increases involvement</td>
<td>37.7% ((20))</td>
<td>Opportunity</td>
</tr>
<tr>
<td>Novelty</td>
<td>New way to learn</td>
<td>26.4% ((14))</td>
<td>Opportunity</td>
</tr>
<tr>
<td>Convenience</td>
<td>Easy to use</td>
<td>26.4% ((14))</td>
<td>Opportunity</td>
</tr>
<tr>
<td>Sharing</td>
<td>Make connections in new ways</td>
<td>22.6% ((12))</td>
<td>Opportunity</td>
</tr>
<tr>
<td>Sharing</td>
<td>Difficult to use in small groups</td>
<td>18.9% ((10))</td>
<td>Limitation</td>
</tr>
</tbody>
</table>
Discussion

The purpose of this study was to determine if iLearning improved perceived learning and perceived engagement in undergraduate students enrolled in an introductory human anatomy and physiology course. We found that the use of iLearning activities did not change perceived learning but did significantly affect perceived engagement. However, the results indicated that the significant change to engagement was negative, meaning students perceived less overall engagement through iLearning than what they had expected at the start of the semester. At both time points, there was a strong and significant correlation between perceived learning and perceived engagement through the use of iPads in class. Therefore, the research hypotheses were not accepted.

Perceived Learning

Perhaps the absence of a change in perceived learning with iLearning activities was due to the creation of a ceiling effect by the mean scores at pre-data collection, leaving little room to improve toward the 30-point maximum on the survey scale. It is possible students overstated their perceived learning at the start of the semester and, in fact, realized a high level of learning through iPad activities for the duration of the semester. Compared to the original study by Rossing and coworkers (2012), mean scores for this dimension were higher for every question except number 3. Therefore, the students’ initial, relatively positive perception of how Learning could augment their learning may have diminished any intervention effect seen after using the technology.

Confidence (question 5) was the only construct in the perceived learning dimension to significantly increase from start to end of the semester. iLearning expands the possibility in the classroom by offering a hands-on option for a wide range of student abilities, which allows individuals to move through the material at their own pace. In a study of undergraduate students enrolled in an introductory human anatomy and physiology course, a majority (78%) indicated the use of an iPad improved mastery of content (Chakraborty and Cooperstein 2017).

Similarly, 20 students (37.7%) in the present study appreciated the ability of the interactive, 3-dimensional pictures to help them visualize complex concepts when using the iPad. It has been shown that students perceive an increased effectiveness of learning with computer-based interactive imagery compared to paper-based static imagery (Khalil et al. 2005). By integrating iLearning strategies, students control their learning process rather than relying completely on knowledge transfer from faculty (Bailey et al. 2015). Thus, students can gain confidence in course content through self-paced and interactive learning methods. Innovative approaches to improve collaborative learning changes the traditional classroom and offers the student more influence on their learning as opposed to a teacher-driven model.

Research suggests connecting iLearning in the classroom to course objectives is an effective way to reach students and augments student-faculty interaction (Rossing et al. 2012; Sample 2011; Wilkinson and Barter 2016). Rossing and colleagues (2012) studied combined teaching styles and found students perceived the use of tablets to be helpful to the learning process. Specifically, students reported the ability to connect to ideas in new ways and that tablets provided additional opportunities to apply course content to solving problems (Rossing et al. 2012).

In the present study, the constructs of content application, learning, and connecting new ideas were not significant between the pre- and post-surveys. However, the survey question means were very high at both time points. In fact, of the 636 responses in this survey dimension, only 31 were either disagree or neutral on the Likert scale. Therefore, the present study may reflect that the students sampled were open to perceived learning through iLearning teaching strategies from the start of the semester. The introduction of technology does take intentional design, but the opportunity exists to incorporate a high-impact practice to supplement teaching pedagogy.

Conversely, the integration of iLearning may have had a non-significant effect on perceived learning due to inherent shortcomings of the technology and its accessibility. The iPads were only available during class or the professor’s office hours. This time constraint may have limited how students could apply, connect, or participate with iLearning methods. Moreover, the use of tactile learning with anatomical models was condensed to provide time for integration of new iLearning activities. Students have been shown to enjoy the tactile sensation of using an actual anatomical model (Yammine and Violato 2015). Finally, for any interface, time is often needed to gain comfort in the intricacies of how it works, no matter how intuitive the student of today is with screen-based technologies. In fact, uncooperative technology was the most commonly expressed limitation, noted by 22 subjects (41.5%). Future research should consider evaluation of best practices to understand preferences and the association to course outcomes through the integration of multiple sensory approaches in a traditional undergraduate classroom.

Perceived Engagement

There was a significant, negative change in perceived engagement throughout the semester; meaning that students noted less engagement through iLearning at post-data collection than what they had anticipated at the start of the semester. In contrast to the original study by Rossing and coworkers (2012), the only significant changes seen throughout the semester were in questions 8 and 10. For question 8, students felt they participated less with the iPads than expected. This group of students may have preferred more traditional learning methods to iLearning, leading to the present study results. Answers to question 10 at post-data collection on the 636 responses in this survey dimension, only 31 were either disagree or neutral on the Likert scale. Therefore, the present study may reflect that the students sampled were open to perceived learning through iLearning teaching strategies from the start of the semester. The introduction of technology does take intentional design, but the opportunity exists to incorporate a high-impact practice to supplement teaching pedagogy.

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collection indicated that students felt the iPad was a more convenient iLearning device compared to a traditional laptop or computer compared to at the beginning of the semester. Moreover, 32 students (61.5%) agreed that iLearning activities were an important and effective tool for the course. However, the group difference seen for perceived engagement by the end of the semester in the present study was ultimately significant in a negative direction. It is possible the high survey scores at the beginning of the semester prevented any meaningful change to be seen.

Previous research has shown that technology may afford the personalization of learning by offering students autonomy and empowerment in the process no matter the number of students enrolled in a course (Wilkinson and Barter 2016). Sample (2011) found that the use of technology in course design may be able to adapt to a variety of faculty to student ratios to ensure student engagement remains high while keeping the focus on course content. Class size may have played a role in the unexpected results in perceived engagement.

In the present study, the typical ratio of students per iPad ranged from 1 to 3 at any given time. Ten iPads were available for iLearning with an average lecture size of approximately 23 students and an average lab size of about 15 students. Because these students did not have a personal iPad throughout the semester, their perceived engagement may have been stifled. Specifically, 22.6% (n = 12) of students provided a negative response to question 8. These students felt they participated less in class with the iLearning activities than activities without. And 10 students (18.9%) commented that it was difficult to complete the iLearning activities in small groups. This was despite the other opportunities mentioned, such as the convenience of using an iPad versus a computer or the larger screen size compared to using an app on a standard cell phone. Ultimately, the design of this introductory human anatomy and physiology course includes a variety of teaching strategies to engage students. As a whole, there was a negative, significant change in perceived engagement due to iLearning. However, the results showed some support of multiple teaching methods rather than an over-reliance on iLearning.

Previous research has shown that instituting group work with technology bolsters confidence in and overall understanding of course content (Laal and Ghodsi 2012). Examples of group work in the present study included identification of structures through the images provided in the app, watching videos explaining human physiology of specific systems, and trying randomized quizzes by completing worksheets while using the iPads. There was a slightly greater but non-significant improvement in student responses to question 11, wherein there was a positive indication of collaboration using an iPad compared to other group activities. Moreover, 14 students (26.4%) appreciated the new way to learn content and 12 students (22.6%) stated that iLearning allowed them to make connections to course content while working with their peers.

Likewise, previous research showed that mobile technology provided greater opportunities for collaboration and dynamic learning (Rossing et al. 2012). Again, the negative change may reflect a preference for learning through other forms of engagement or a consequence of the fact that signal measurements at the start of the semester were quite high.

Only 24 responses for the entire dimension were either disagree or strongly disagree. As stated earlier, the current generation of students is intuitive with touch screen technology. However, interaction with iLearning requires a slight learning curve and these activities can lead to frustration. Rossing et al. (2012) indicated undergraduate students use smartphones but may not have the capacity to apply those skills to critical thinking situations. Furthermore, with the typical student-to-iPad ratio mentioned above, the comfort levels of individual students may have varied. The instructors provided specific, guided classroom activities in an attempt to increase comfort and engagement without frustration. These factors may, in part, be responsible for the negative changes to the dimension of perceived engagement after a semester of iLearning. Instructors looking to add iLearning to their courses should ensure familiarity with the technology before activities and assessments occur.

Student perceptions of the convenience of iLearning (question 10) were significantly changed in a positive direction. Previous studies found that students believed iPads to be a useful tool to increase flexibility, portability and productivity because they are small in size and easy to use (Alyahya and Gall 2012; Rossing et al. 2012). Perez et al. (2011) found student perceptions were positive about using iPads in their learning, but there was no evidence of better learning outcomes. In the present study, the aggregate class final average grade did not significantly change after implementation of iLearning. Future research could focus on finding how iLearning can benefit student retention of specific introductory human anatomy and physiology course objectives through analysis on measurable course evaluations.

**Conclusion**

Technology will continue to shape our everyday lives and the undergraduate classroom is not exempt. Educators must continually evaluate technology’s effectiveness and pedagogical applications. This study sought to build upon the growing body of research regarding the perceived effectiveness of technology, specifically iLearning, in the classroom. In summary, the addition of iLearning did not result in significant, positive changes to perceived learning and perceived engagement through an academic semester. However, responses to both perceived learning and engagement at both time points were mostly on the positive end of the survey Likert scale. Therefore, the use of iLearning in an introductory human anatomy and physiology course is encouraging, though additional research is needed to establish best pedagogical practices to maximize both perceptions and outcomes.

continued on next page
About the Authors

Michael “Cody” Huisman, DC, CSCS, was most recently an assistant professor of Exercise Science at Central College. He taught courses in human anatomy, physiology and kinesiology. Cody’s research interests include functional movement patterns as they relate to athletic performance and improving pedagogy through technology. Katelin Valster, PhD, CSCS is a lecturer of Exercise Science and a pre-health and post-graduate advisor. Her research interests include community health education program implementation, psychological and physiological influences on sport performance, and teaching pedagogy (i.e., service-learning).

References


APPENDIX 1: iLearning Survey

You are invited to participate in a survey to get your feedback on the effects of using iPads in the classroom. Your participation is completely voluntary and anonymous. Whether or not you complete this survey will have no bearing on your grade in this class. You may choose to skip any question you do not want to answer and stop completing the survey at any time.

Select how strongly you agree or disagree with the following statements.

<table>
<thead>
<tr>
<th>The iPad activity (OR a specific application) may help me</th>
<th>Strongly Agree</th>
<th>Agree</th>
<th>Neutral</th>
<th>Disagree</th>
<th>Strongly Disagree</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. apply course content to solve problems.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2. learn the course content.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>3. connect ideas in new ways.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4. participate in the course activity in ways that enhanced my learning.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5. develop confidence in the subject area.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6. develop skills that apply to my academic career and/or professional life.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>7. The iPad activities will motivate me to learn the course material more than class activities that do not use the iPad.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8. I will participate more in class during the iPad activities than during activities that did not use the iPad.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>9. My attention to the task(s) will be greater using the iPad.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>10. The iPad is more convenient compared to a desktop or laptop computer</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>11. It is easier to work in a group using the iPad than in other group activities.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>12. iPad activities will be an important supplement to this class.</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

13. Describe how the iPad activity may help or limit your learning of the class content.

14. Describe at least 2 things you anticipate liking about using iPads in this class:
   a. 
   b. 

15. Describe at least 2 things you anticipate disliking about using iPads in this class:
   a. 
   b. 

Tell us about yourself

<table>
<thead>
<tr>
<th>Age</th>
<th>Under 18</th>
<th>18 – 28</th>
<th>29 – 44</th>
<th>45 and over</th>
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<td>16. Age</td>
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<td>17. Gender</td>
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18. Before using iPads in this class, what was your comfort level using handheld mobile computing devices?
   [ ] Not at all comfortable
   [ ] Not very comfortable
   [ ] Fairly comfortable
   [ ] Very comfortable

continued on next page
19. How likely are you to use a handheld mobile computing device for e-learning or professional development?

[ ] Not likely
[ ] Somewhat likely
[ ] Likely
[ ] Extremely likely
[ ] Unsure

20. Considering face-to-face classes that use e-learning technology (such as handheld devices, online research guides, Oncourse, or other course management systems) in the classroom, which of the following best fist your preference?

[ ] Classes that make little or no use of e-learning technology.
[ ] Classes that use a moderate amount of e-learning technology.
[ ] Classes that make extensive use of e-learning technology.
[ ] No preference.

21. Do you own a handheld mobile computing device that is capable of accessing the Internet (whether or not you use that capability)? Examples include iPhone, BlackBerry, other Internet-capable cell phone, iPod touch, PDA, iPad, Kindle, etc.

[ ] No, and I don’t plan to purchase one in the next 12 months.
[ ] No, and I plan to purchase one in the next 12 months.
[ ] Yes.
[ ] Don’t know.

22. If yes, how do you use handheld mobile computing devices? Check all that apply.

[ ] Access course management systems
[ ] Access other e-learning tools
[ ] Browse the Internet
[ ] Download and listen to music
[ ] Download and listen to podcasts/audio books
[ ] Download and read e-books/print-based content
[ ] Download and view streaming movies/video clips
[ ] Make phone calls
[ ] Play interactive games
[ ] Search for information
[ ] Send and receive e-mail
[ ] Send and receive instant messages (IMs)
[ ] Send and receive pictures (MMS)
[ ] Send and receive short text messages (SMS)
[ ] Use camera to take and share pictures
[ ] Banking
[ ] Calendar
[ ] Maps
[ ] News
[ ] Shopping
[ ] Social networking
[ ] Sports
[ ] Twitter
[ ] Weather
[ ] YouTube
[ ] Other. Please specify: ____________________________

The survey is borrowed from:

Permission for reproduction and use of the survey was granted on June 25, 2018.
APPENDIX 2

Permission to use the Rossing et al. (2012) iLearning survey:

-------- Original message --------
From: "Rossing, Jonathan" <rossing@gonzaga.edu>
Date: 6/25/18 1:47 PM (GMT-06:00)
To: Katelin Gannon <gannonk@central.edu>
Subject: RE: iPad technology survey

Hello Katelin,
Thanks for your message.
You’re welcome to use the survey understanding that you’d cite the article in any presentation or publication as well.

Best wishes with your work.
Jonathan

JONATHAN P. ROSSING, PhD | Gonzaga University | Associate Professor and Department Chair, Communication Studies | P 509-313-6958 | rossing@gonzaga.edu

GONZAGA UNIVERSITY
The Benefits of Multimodal Interactive Case Studies

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Abstract
It is hypothesized that creating case studies that are visually and kinesthetically interactive will encourage experiential and active learning, as well as enhance student engagement and a sense of enjoyment in learning. The case studies in this study were designed to incorporate reading, visual imagery, as well as auditory and hands-on activities for the students. Specifically, each question created has an experiential and/or active component as well as immediate electronic auto-feedback. It was expected that students would find the incorporated images, video clips, interactive websites, as well as hands-on plastic models appealing as well as helpful in their learning. Additionally, it was anticipated that the case studies would assist with remembering key aspects of pathophysiology for the final exam. The four case study topics focus on peptic ulcers, cardiovascular diseases, diabetes, and bone fractures coupled with osteoporosis and sciatica. In addition, each case study begins with reflective questions that are designed to add a metacognitive component to each lesson. Surveys were given after each case study to gauge student satisfaction. In addition, final exam questions responses were analyzed for signs of improvement. https://doi.org/10.21692/haps.2021.011

Key words: pathophysiology, case studies, interactive, images, video clips, kinesthetic, tactile, visual, digital, multimodal, feedback

Introduction
Many studies have shown that using interactive learning strategies can help with increasing students’ enjoyment, cognitive processing, and retention of new knowledge (Abykanova et al. 2016, AAAS 2015, Callary et al. 2018, Hyun et al. 2017). Increasingly popular in lesson plans, the AAAS reported that active learning emphases have been increasing in lecture courses since 2012 (AAAS, 2015). This shift has led to positive outcomes being reported. Hyun et al. (2017) studied the implementation of active learning in sixteen courses and found that active learning was associated with higher student satisfaction when introduced in both traditional classrooms, as well as active learning classrooms. Callary et al (2018) reported that incorporating various active components into their lesson plans (e.g. writing, discussion, visual gallery stations, reflection, scavenger hunts, and community engagement) built confidence and fostered curiosity, as well as inner motivation.

Furthermore, research has also found that student-centered activities, involving problem solving, collaboration, student accountability, and teacher management strategies were very effective when acquiring higher order skills (Brush and Saye 2000). In a review of the literature, Abykanova et al. (2016) found that interactive technology activities led to greater mastery of material and more productive communication between students in the classroom, as well as between students and their instructor. They did note that extensive lesson planning and organization on behalf of the instructor is required for optimal success.

As a note of caution, however, Cossom et al. (1991) found that case-based instruction does not appeal to all learners and that some students’ needs are not met. Therefore, additional strategies or resources may be required. Furthermore, in reviewing the literature, Ertmer et al. (1995) stated that assuming case-based instruction increases problem solving and critical thinking abilities in all students is likely not accurate. They investigated whether individual self-regulation (motivation and reflection) abilities may play a factor in the varying beneficial impacts of case-based learning within a veterinarian program. They found this was the case and that student success also depended on the students’ goal orientations for the course, their strategies (process or product) for completing assignments, their openness to challenges, and other factors affecting personal life and confidence, as well as the format of the case study (Ertmer et al. 1995). Interestingly, this study found that problem-based learning increased student confidence and motivation particularly with students who had scored lower for self-regulation.

Furthermore, Fukuzawa et al. (2017) found that problem-based learning increased student confidence and motivation particularly with students who had less subject matter experience. It is also worth keeping in mind that metacognitive pieces coupled with active learning have been demonstrated to further increase student success. Mutambuki et al. (2020) found that implementing a 50-minute metacognition lesson...
in their active learning lessons led to increases in exam scores compared to the use of active learning on its own. Specifically, in their metacognition lesson, they showed students how to plan studying, monitor self-learning, and evaluate one’s own understanding and performance.

As mentioned, many different active learning tools have been used in higher education, including interactive learning objects such as: interactive patient-based case studies (IPCS), review games, simulated interactive patients (SIP), flashcards, and unit quizzes (Reilly 2011). Specifically, within a 1st year medical school anatomy course, Reilly (2011) found that having interactive learning objects significantly improved learner written examination scores, and the SIP learning technique was the most helpful. Reilly (2011) also found that students rated the simulated interactive patients (SIP) and interactive patient-based case studies (IPCS) more favourably than the other activities (e.g. review games).

The use of electronics, such as online case studies has also been shown to allow the students a chance to improve critical thinking skills and be more involved with the course content (Richman 2015). Further, case studies have been found to help students develop problem-solving skills, encouraged reflection and decision making, and allowed the analysis of problematic situations from different levels and points of view (Kunts & Hessler, 1998 as cited in Richman 2015). Case-study-based instructional methods can be more engaging to students compared to traditional instruction, and were preferred by students in a management course (Abeysekera 2015). In addition, Hebert and O’Donnell (2020) found that developing targeted case studies improved student performance on related exam questions. This suggests that assisting students with extra practice questions and study materials that focus on learning outcomes can be appealing as well as beneficial.

Furthermore, Smee and Cooke (2018) found that case studies are an excellent way of ensuring students acquire higher order skills and understanding of course material. Rather than utilizing rote memory, students developed a better and more thorough understanding of physiological systems and acquired greater understanding and insight into real-world applications (Smee and Cooke 2018). Brush and Saye (2000) demonstrated that learning activities such as case studies added to the relevancy of course material and provided students with opportunities to collaborate and solve real-world problems.

It is important to note that Brush and Saye (2000) provided tips on designing active learning activities, and specifically recommended employing a high degree of structure to avoid student disorientation and frustration. Furthermore, they stated that it is important to be cognizant of the following assumptions that are made regarding learning activities and these assumptions should be taken into account by the instructor before designing such activities. First, it is often assumed that the student is willing and able to take on more responsibility for their learning compared to traditional learning activities. In addition, it is often assumed that students are able to self-manage and self-evaluate as well as to set goals. Also, if activities take the form of group-activities, it is often assumed that students have the skills required for successful collaborative learning. Therefore, to ensure success, it is recommended that instructors provide well-defined questions and rubrics, timely feedback, metacognitive pieces, and assistance with setting roles and accountability for both individual and group-work (Brush and Saye 2000).

With this previous research in mind, the case studies created in this study were designed to incorporate many of these ideas: prior knowledge, structure, clarity, immediate feedback, individual accountability, logical flow, metacognition, and active learning. Specifically, this study evaluated the effectiveness of incorporating various stimuli (visual, auditory, tactile, and electronic) into pathophysiology case studies for 2nd year Nursing students and 3rd year Human Kinetics students. The goal was to design case studies that were less text-heavy and potentially more student-centric by creating multi-modal study resources that incorporate various components (e.g. pictures, video clips, animations, manipulatives, and interactive electronic components).

Interestingly, the metacognitive activities we used at the beginning of term revealed that the majority of both the 2nd year nursing students and the 3rd year human kinetics students participating in this study stated that their preferred learning resources were interactive (e.g. hands-on, either tactile or electronic), followed closely by reading/writing, auditory (listening and speaking), and visual (including pictures, video clips, and animations). This is slightly different in comparison to the 3rd year nursing students at a Jordan University who reported read/write as their dominant learning preference, followed by kinesthetic (Alkhasawneh et al. 2008). Though, Alkhasawneh et al. (2008) made clear that most 3rd year nursing students in their class did report having multimodal learning preferences overall which is similar to our findings. Additionally, we noted that most students in our classes preferred to come to class and learn through images, listening, and activities rather than reading the textbook on their own. To that end, the goal in our course was to provide course material in many different formats making it accessible to all of our students, with interactive case studies being a contributing component.

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Methods
Multimodal case study assignments were created for two different pathophysiology courses, reflecting each class’s unique learning outcomes. The 113 students enrolled in 2nd year Nursing Pathophysiology and the 201 students enrolled in 3rd year Human Kinetics Pathophysiology were asked to complete graded case study assignments as well as voluntary, optional, ungraded, pre- and post-case study surveys. All case studies were given to the students after they had classes in each topic. Equipped with this prior knowledge, students could engage with the case studies to improve and master their understanding of the concepts. It was hoped that students would use the case studies as they started studying for their exams. The students were able to complete each case study as many times as they wished and their highest score for each was the one that counted towards their final grade.

All case studies were assigned as homework and were completed individually, though students were welcome to work in groups if they chose. The case study format used was Appraisal Case Studies format as depicted in O’Malley et al. (2019) in which the student must use problem solving skills and critical thinking to determine what is happening with the patient, what the diagnostic test results mean, and review each disease’s pathophysiology, risk factors, signs and symptoms, possible complications and typical outcomes.

This project was approved by UBC’s research board of ethics. This educational research project was explained in detail to all of the students in advance and students were given consent forms to read over and sign if they were willing to have their data used for this study. Participation was voluntary and students were able to change their minds and withdraw from the study at any time.

As part of the study, case study data was linked to scores on related final exam questions to observe any influence on long-term memory and performance. It should be mentioned that final exam questions were purposely quite different from those in the case studies. However, it was anticipated that case studies would bolster knowledge of these topics in general, leading to a better understanding of the topics as a whole, and higher final exam scores. The case study survey data was blinded to the course instructor. Personal identifiers were removed from the data by a 3rd party prior to data analysis to maintain anonymity and confidentiality. Statistical analysis in each data set involved using paired t-tests as well as Pearson correlational analysis.

Results and Discussion
A. Osteoporosis and Fracture Case Study
In this case study, 2nd year nursing students were introduced to a story in which two neighbors of differing ages (89 and 40 years old) came to have bone fractures. As students worked through the case study, they were taken through the different risk factors, the pathogenesis, diagnostic tests, treatments, possible complications, as well as the healing that occurred in both cases. The interactive components of this case study consisted of: 3 x-ray images, 1 DXA image, 4 plastic models representing the progressive stages of vertebral osteoporosis and disc degeneration, 1 image of sciatica, and 1 figure illustrating the 4 stages of bone fracture healing.

Prior to going through the case study, in order to gauge prior knowledge and add a reflective piece, students completed a short survey in which they rated their level of understanding of the risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical treatments of both bone fractures and osteoporosis. Pre-case study survey results are depicted in Figure 1 and show that on average, prior to starting the case study, most students felt they had room for improving their mastery of course content in each area. Specifically, only 7-21% (4-12) of students selected “Excellent” in response to these questions. Furthermore, most (22-32 or 39-57%) respondents rated their level of understanding of each aspect of bone fractures and osteoporosis as “Good”. It is not surprising that “Poor” was selected less often (1-10 or 2-18% of students) in answer to these questions, as students completed the case study after attending classes on both topics (bone fractures and osteoporosis). Pre-case study survey results are depicted in Figure 1 and show that on average, prior to starting the case study, most students felt they had room for improving their mastery of course content in each area. Specifically, only 7-21% (4-12) of students selected “Excellent” in response to these questions. Furthermore, most (22-32 or 39-57%) respondents rated their level of understanding of each aspect of bone fractures and osteoporosis as “Good”. It is not surprising that “Poor” was selected less often (1-10 or 2-18% of students) in answer to these questions, as students completed the case study after attending classes on both topics (bone fractures and osteoporosis). Likewise, only 0-1 students selected “I Haven’t Learned Yet”.

In considering possible future enhancements to the course, It was noted that prior to the case study, students were least confident in their understanding of diagnostic tools for bone fractures and osteoporosis, with 9-10 students selecting “Poor” in answer to those two questions respectively. On the other hand, students were most confident in their ability to identify risk factors for bone fractures and osteoporosis as well as typical outcomes for bone fractures.
The Benefits of Multimodal Interactive Case Studies

Figure 1. Student Reflective Knowledge Survey - Completed Before and After the Fracture and Osteoporosis Case Study. Students rated their understanding of aspects of a) Bone Fractures and b) Osteoporosis. Possible choices to each statement were: Excellent, Very Good, Good, Poor, and I Haven’t Learned Yet.
The survey results after their first and second attempts of the case study are also shown in Figure 1. The majority of respondents felt that they improved in the mastery of each topic after each attempt at completing the case study. After the first attempt, between 37-43% (13-15) of respondents selected “Excellent” and only 0-2 (0-6%) respondents selected “Poor” when rating their understanding of various aspects of bone fractures and osteoporosis.

The average case study score of the 54 respondents on Attempt 1 was 21.92/30 (73%) and the average score of the 35 respondents on Attempt 2 was 29.40/30 (98%). For the 35 students that completed the 2nd attempt, there was an average improvement of 6.8 points (23%). For these 35 students, the difference between the Attempt 1 and Attempt 2 scores was found to be statistically significant (with alpha=0.05). Specifically, results of paired t-tests between Attempt 1 and 2 case study scores found the t-statistic value to be -20.086 and the t-critical value to be 2.032 (and therefore the null hypothesis was rejected).

None of the students indicated a decrease in their understanding of the material on subsequent case study attempts. All students chose either a higher rating or the same rating as on their previous attempt.

11 Students completed the case study a 3rd time and of the 8 students that completed the survey at the beginning of their 3rd case study attempt, an even higher proportion of students (55-64%) selected “Excellent” in response to these questions, and the remaining students selecting “Very Good” most often, followed by “Good”. None of the students selected “Poor”, or “I Haven’t Learned Yet”. Results are shown in Figure 1 (labelled “Post 2nd attempt”) and increasing student confidence trends with each topic are depicted after every case study attempt.

Once the students had completed the Osteoporosis and Fracture Case Study they were invited to complete a second set of optional survey questions which was designed to assess their perceived level of understanding of the risk factors, pathogenesis, treatments, diagnostic tools, healing stages, and possible complications of both osteoporosis and bone fractures. This set of survey results is shown in Figure 2. The majority (85%) of students agreed that this case study helped them understand the different options for treating hip fractures. 97% of students agreed that this case study helped them understand the 4 healing stages of bone fractures, 94% agreed that it helped them understand what happens to the bone during osteoporosis, and 79-85% of students agreed that it helped in understanding osteoporosis risk factors such as hormone imbalance, kidney disease, and diabetes. 91% of students agreed that this case study helped them understand how osteoporosis is diagnosed and 76-88% of students agreed that it helped them understand how osteoporosis can lead to vertebral compression, bone spurs, sciatica, and even hip fractures and death.

Figure 2. Student Satisfaction Survey - Completed After the Osteoporosis and Fracture Case Study. 2nd year nursing students rated the case study’s abilities to promote learning of different aspects of these topics. Possible ratings of each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
In addition to the questions asked in Figure 2, students were able to fill in an optional comment box as well (Appendix, Table 1). Positive comments included sentiments that the case study was: engaging, fun, useful, interactive, enjoyable, helpful, relevant to the real world, and well done. Suggestions included giving immediate feedback after each question. While we agree that this is a very good idea, it is not possible with our current Learning Management System (LMS). Our current LMS (Canvas) gives feedback immediately after the student has finished and submitted all of the questions. That being said, not having immediate feedback on each question might encourage students to look things up on their own and take the case study again which may foster more long-term memory of the material. As mentioned previously, students were given unlimited attempts at the case study to encourage its use as a learning and studying tool.

There was a suggestion that the content did not align with the course which is unfounded. Another suggestion was to make the images smaller which is possible and something that will be looked into doing in the future. The goal was to have the images large enough for everyone to see clearly no matter what device they use. Three students wanted the case study to be shorter. The case study was 27 questions and worth 30 points. It was open book and there wasn’t a time limit, so students could leave the case study running on their computer and take breaks while they were completing it. Indeed, 9 students had very long run times for Attempt 1 (3hr 8min to 1131hr 22min). With these times removed from calculations, students took an average of 32min 13sec on their first attempt. It was anticipated that students would take less time on subsequent attempts, which proved true, with students taking an average of 9min 15sec on their second attempt.

As mentioned, once the students had completed the Osteoporosis and Fracture Case Study they were invited to complete a second set of optional survey questions. Included in this survey were questions designed to assess the various components of the case study to see which were found to be helpful. The results of the case study component survey question are shown in Figure 3. The majority (76-97%) of students agreed that the visual (x-ray images and figures), as well as the interactive and hands-on components (electronic osteoporosis risk tolerance test and plastic models) were helpful in their learning. 85% of students agreed that this case study would help them remember specific details of bone fractures, osteoporosis and disc degeneration. 94% of students agreed that case studies like this should be used in the future.

![Figure 3. Student Survey Completed on Osteoporosis and Fracture Case Study Components. 2nd year nursing students rated the usefulness of the various multimodal aspects of this case study. Possible ratings of each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.](image-url)
B. Heart Disease Case Study

In this case study, 2nd year nursing students were introduced to a story in which a client visits the doctor after experiencing blurry vision, headaches, and heart palpitations when climbing the stairs to his apartment. Over the course of 24 questions, students were taken through the risk factors, signs and symptoms, and diagnostic tests associated with both peripheral artery disease and coronary artery disease. Possible complications and pathogenesis of angina pectoris, myocardial infarction, hypertension, congestive heart failure, nephrosclerosis, ischemic and hemorrhagic stroke, retinopathy, metabolic syndrome and non-alcoholic fatty liver were also explored.

The interactive components of this case study consisted of: 17 images and 8 plastic models (which depicted atherosclerosis, angina pectoris, myocardial infarction, congestive heart failure, nephrosclerosis, retinopathy, non-fatty liver disease, ischemic and hemorrhagic strokes). The images included a CT angiogram and a Doppler ultrasound image of peripheral artery disease in the leg.

LMS reporting indicated that students took an average of 16 min 45 sec to complete this case study. It was found that 2 students left their case studies running for more than 34 hr and these two data points were not included in the calculation. Students took longer on their first attempt (averaging 23min 13sec) and then less time on their subsequent attempts (with Attempt 2 averaging 10min2sec).

Prior to going through the case study, students could opt to complete the survey depicted in Figure 4 in which they rated their level of understanding of the risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical treatments of hypertension, angina pectoris, and heart failure. This case study was given to students after we had a class in this unit so it was not surprising that “I Haven’t Learned Yet” was selected the least often in answer to these questions and “Poor” was selected by only 2-6 (5-18%) students depending on the question. Additionally, survey results show that prior to the case study, most students felt they had room for improving their mastery of this course content in each area, which was also anticipated. Only 23-35% (9-14) of respondents selected “Excellent” in response to these questions.

When considering future course enhancements, it was noted that, prior to the case study, students were least confident in their understanding of diagnostic tools for congestive heart failure and typical outcomes for hypertension and angina pectoris, with 7 and 6 students selecting “Poor” in answers to those questions respectively. This is not surprising as there are many diagnostic tools for CHF and many typical outcomes for both hypertension and angina pectoris depending on duration and severity making these complex topics to learn with confidence. On the other hand, students were most confident in their ability to identify risk factors for hypertension which are concepts that are more intuitive and commonly known.


Figure 4. Student Reflective Knowledge Survey - Completed Before and After the Heart Diseases and Disorders Case Study. Students were asked to rate their understanding of aspects of a) Hypertension, b) Angina Pectoris, and c) Congestive Heart Failure. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.

continued on next page
The Benefits of Multimodal Interactive Case Studies

In the post-case study survey (Figure 4), the majority of respondents reported that they improved in the mastery of each topic after completing their first attempt at the case study. Between 28-40% (7-10 of respondents selected “Excellent” in response to these questions. Only 0-3 (0-12%) respondents selected “Poor” when rating their understanding of various aspects of hypertension, angina pectoris and heart failure.

The average score of the 40 respondents on Attempt 1 of the case study was 26.67/31 (86%) and the average score of the 25 respondents on Attempt 2 was 27.58/31 (89%). For the 25 students that completed the 2nd attempt, there was an average improvement of 1.1 points (3.5%). The difference between Attempt 1 and Attempt 2 scores was not found to be statistically significant (with alpha=0.05). Specifically, results of paired t-tests between Attempt 1 and 2 scores found the t-statistic value to be 0.26 and the t-critical value to be 2.06 (and therefore the null hypothesis was accepted). It should be noted that students who scored high on their first attempt, were less likely to repeat the case study compared to students who scored lower. This is likely a factor in both overall score improvement was well as survey responses.

Once the students had completed the Heart Disease Case Study, they were invited to complete a second set of optional survey questions which were designed to assess the student’s perceived level of understanding of the risk factors, signs and symptoms, pathophysiology, diagnostic tests of hypertension and heart disease. Additionally, students were asked if this case study helped their level of understanding of angina pectoris, peripheral artery disease, different types of CVA, and the effects of hypertension on the kidney, brain, and eyes. This set of survey results is shown in Figures 5 and 6.

The responses indicated that the majority of students (79-100% or 33-42 of 42 student responses to this set of 10 questions) agreed that this case study helped them understand all of those specific topics. The lowest score, though still very favorable had 33 (79%) of students agreeing that the case study’s coverage of CVA was helpful. It is not surprising that students weren’t able to learn as much about the various types of CVA from this case study compared to other topics. CVA was covered predominantly during class and is only briefly mentioned during the case study. The case study’s depiction of the effects of hypertension on the kidneys, eyes and vision was almost unanimously reported to be helpful, which was wonderful, as our students typically find nephrosclerosis and retinopathy as a result of hypertension difficult to picture and understand. It is thought that the plastic eye and kidney disease models were helpful with this.

The topic of peripheral artery disease (PAD) in the case study was reported 2nd most often (by 39 or 93% of respondents) as being helpful in their understanding. This topic did have the most pictures incorporated into the case study which may have contributed to this success. Specifically, there were 3 different pictures of PAD (a drawing, a Doppler ultrasound image and an angiogram) in addition to a picture of blood pressure readings in the leg, making this topic the most visual in the case study.

**Figure 5.** Student Satisfaction Survey - Completed After the Heart Diseases and Disorders Case Study. 2nd year nursing students rated the case study’s abilities to help the learning of different facets of heart diseases and disorders. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
As depicted in Figure 6, the majority (37 or 88%) of the respondents agreed that this case study should be used in the future. Most students (32-39 or 76-90%) agreed that the pictures, plastic models, real histology pictures, angiograms, Doppler imaging, and creation of study table during this case study were helpful in their learning. One of the goals of the class is to make connections between the cardiovascular system and the health of all organ systems. Most students (95%) agreed the case study helped them appreciate how the cardiovascular system is important to all organ systems. Additionally, 86-90% of students found the visual and interactive aspects helpful and engaging.

### C. Diabetes Case Study

In this case study, 2nd year nursing students were introduced to a story in which three members of a family are each experiencing a different type of diabetes (Type 1, Type 2, and gestational diabetes). Over the course of the case study’s questions, students were taken through the risk factors, pathogenesis, diagnostic tests, treatments, possible

Students were able to leave comments in this survey (Appendix, Table 2). Most comments were favorable, citing appreciation of the interactivity, the mock real life situation, the pictures, the compartmentalization of a specific topic, and the ability to test and reflect on one’s own knowledge. Suggestions again included providing immediate feedback after every question instead of at the end.

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**Figure 6. Student Survey on Heart Disease Case Study Components.** 2nd year nursing students rated the usefulness of the various multimodal aspects of this case study. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
complications, and outcomes that are typically associated with gestational diabetes. The interactive components of this case study consisted of: step-by-step pictures of urinalysis and pictures of blood testing and fetal monitoring. Also, in addition to completing this first part of this case study which was largely dedicated to gestational diabetes, students also completed “The Role of Insulin Video Quiz” and “The Diabetes Pathophysiology Video Quiz”, both of which focused on both Type I and Type II diabetes. These two video quizzes are 5 and 23min. videos embedded with quiz questions.

Prior to going through the case study and associated video quizzes, students completed an optional survey (Figure 7), in which they rated their level of understanding of the risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical treatments of gestational diabetes. The responses before the case study, indicated that the majority of the respondents felt that they still had room for improvement in the mastery of each topic. Specifically, only 17-26% (9-14) of respondents selected “Excellent” in response to these questions. The most common response to these questions was “Good”, which was chosen by 16-22 (30-42%) students. “Poor” and “I Haven't Learned Yet” were selected least often which is not surprising as this case study was delivered after the material was covered in class, and class attendance is close to 100%.

For future consideration in course design, it was noted that students were least confident in their understanding of pathophysiology and typical outcomes for diabetes, with 8 (15%) students selecting either “Poor” or “I Haven't Learned Yet” in answer to those two questions respectively. On the other hand, students were most confident in their ability to identify risk factors for diabetes with only 5 (10%) students selecting either “Poor” or “I Haven't Learned Yet”.

Figure 7. Student Reflective Knowledge Survey - Completed Before and After the Diabetes Case Study. Students rated their understanding of aspects of Type I, Type II, and gestational diabetes. Possible answers to each question were: Excellent, Very Good, Good, Poor and I Haven't Learned Yet.
When students completed the case study a second time they filled in the survey at the beginning again and the results are shown in Figure 7 (labeled "post-case study"). It was found that the majority of respondents felt that they improved in the mastery of each topic after completing their first attempts of the case study. Between 57-59% (21-22) of respondents selected “Excellent” in response to these questions. None of the respondents selected “Poor” or “I Haven’t Learned Yet” when rating their understanding of various aspects of diabetes.

There were 9 questions in the non-video component of the case study and students took an average of 13min 24sec to complete it. This calculated average does not include the times of 4 students that let their case studies run for over 50 hr. Students took an average of 31min 24sec on their first attempt and 2min 52sec on their second attempt. The average score of the 37 respondents on Attempt 1 was 7.03/9 (78%) and of the 37 respondents on Attempt 2 was 7.28/9 (81%). For the 37 students that completed the 2nd attempt, there was an average improvement of 0.5 points (6%). For students with two attempts, the difference between Attempt 1 and Attempt 2 scores was not found to be statistically significant (with alpha=0.05). Results of paired t-tests between Attempt 1 and 2 scores found the t-statistic value to be -1.12 and the t-critical value to be 2.03 (and the null hypothesis was accepted).

17 Students completed the diabetes case study a 3rd time and of the 13 that completed the survey, 12 (92%) of the students selected “Excellent” in response to these questions, with the remaining students selecting “Very Good”. None of the students selected “Good”, “Poor”, or “I Haven’t Learned Yet” indicating they now felt confident in the material.

As mentioned, the students also watched 2 videos that had been created for them. The Role of Insulin is 5min 50sec long and is embedded with 10 multiple choice questions. The Diabetes Video is 23min 38sec and contains 27 multiple choice questions. Both video quizzes were designed to enhance interactivity, engagement, and Q&A practice of the content being presented on Type I and Type II diabetes as well as the normal role of insulin within the body. The students were invited to participate in a survey to gauge the helpfulness of these two activities (Figure 8). Only 1 student responded that the Diabetes Pathophysiology quiz was not necessary.

On the first survey, many students (15-18 or 28-34%) hadn’t completed the video quizzes yet. Of the respondents who had completed the video quizzes, 19 (73%) students found the Diabetes Pathophysiology Video quiz was either helpful or very helpful and 25 (83%) students found the Role of Insulin Video quiz was either helpful or very helpful. After completing the diabetes case study a second time, more students had completed both video quizzes with only 5 selecting “I haven’t done it yet” (Figure 8). Most students (20) that had completed the video quizzes found them “very helpful”. Additionally, 2 students found them to be “helpful”, meaning that 22 (92%) of respondents that had used the video quizzes found them to helpful or very helpful.

---

**Figure 8. Student Survey Assessing Insulin and Diabetes Video Quiz Components.** Possible answers to each question were: Very helpful, Helpful, OK, Not necessary, and I haven’t done it yet.
Once the students had completed the Diabetes Case Study they were invited to complete a second set of optional survey questions to assess their perceived level of understanding of the signs and symptoms, risk factors, pathophysiology, treatments, diagnostic tools, and possible complications including diabetic ketoacidosis and hypoglycemic shock (Figure 9). The majority of students agreed that this case study helped them understand the role of insulin in the body (86%), the signs and symptoms, risk factors, and pathophysiology of diabetes (77%), the diagnostic tools (82%), and possible complications as well as treatments for both Type I and II diabetes (59-73%).

**Figure 9.** Student Satisfaction Survey - Completed After the Diabetes Case Study. 2nd year nursing students rated the case study's abilities to support the learning of different aspects of the diabetes case study. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
The Benefits of Multimodal Interactive Case Studies

Included in this survey were questions (Figure 10) to assess the helpfulness of the various components of the case study. The responses indicated that the majority (64-82%) of students agreed that the visual (video clips, histology pictures, instrument display pictures, and figures), as well as the interactive and hands-on components (plastic models) of this case study were helpful in their learning. 82% of students agreed that this case study would help them remember specific details of diabetes and 91% of students agreed that case studies like this should be used in the future.

Figure 10. Student Survey Completed After the Diabetes Case Study. 2nd year nursing students rated the usefulness of the various multimodal aspects of this case study. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.

D. Abdominal Pain Case Study

In this case study, 2nd year nursing students were introduced to story in which a 29-year-old female smoker starts to have abdominal pain. Over the course of the case study’s questions, students were taken through the risk factors, pathogenesis, diagnostic tests, treatment, possible complications, and healing that is associated with peptic ulcers. Prior to going through the case study, students completed a survey in which they rated their level of understanding of the risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical treatments of gastric cancer and peptic ulcer disease. The interactive components of this case study consisted of: 3 images, 1 x-ray, 3 video clips (0.5-1.5min. each) and 1 plastic model depicting 4 progressive stages of peptic ulcer disease in comparison to normal gastric lining.

Figure 11 displays the results of the survey conducted before and after the Abdominal Pain case study. The responses indicate that before the case study, the majority of students
felt that they had room for improvement in the mastery of each topic. Only 32-41% (7-9) of students selected “Excellent” in response to these questions, though most respondents did have some confidence in their knowledge prior to the case study. Most respondents rated their level of understanding of risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical outcomes of peptic ulcers and gastric cancer as “Good”, “Very Good”, or “Excellent”, with only 1-2 students selecting “Poor”. Most students attended every class, so would have already had some exposure to these topics though this topic was at the end of term and attendance was dropping a bit.

When thinking of future improvements in the course, it was noted that students were least confident in their understanding of typical outcomes of both gastric cancer and peptic ulcers; these topics were not covered extensively during class time. Reassuringly, students were most confident in their ability to identify treatments for gastric cancer and peptic ulcers, which is something that we had spent more time on during class.

This case study was 17 questions and there was no time limit. LMS reporting indicated that students took an average of 16 min 45 sec to complete this case study (a single data point of almost 151 hr was omitted from the calculation). Again, students took longer on their first attempt (averaging 18min 52sec) compared to subsequent attempts (averaging 7min 28sec).

The average score of the 22 respondents on Attempt 1 was 9.42/17 (55%) and the average score of the 16 respondents on Attempt 2 was 16.22/17 (95%). For the 16 students that completed the 2nd attempt, there was an average improvement of 7.44 points (44%) which was found to be statistically significant (with alpha=0.05). Results of paired t-tests between Attempt 1 and 2 scores found the t-statistic value to be -8.00 and the t-critical value to be 2.131 (and the null hypothesis was rejected). 3 Students completed the case study a 3rd time and improved their scores.

It is not surprising that only 22 students opted to take part in the optional surveys for this case study, as this case study was given near the end of term during the Digestive System Diseases and Disorders unit. By that time, typically students are fatigued, have end-of-term papers and lab reports due for other courses, and have mounting stress with final exams rapidly approaching.

Figure 11. Student Reflective Knowledge Survey - Completed Before and After the Abdominal Pain Case Study. Students were asked to rate their understanding of aspects of gastric cancer and peptic ulcers. Possible answers to each question were: Excellent, Very Good, Good, Poor and I Haven’t Learned Yet.
16 of the 22 students (36%) opted to complete the case study a second time and completed the survey at the beginning again. The survey results therefore depict student responses after they had completed one attempt at the case study and are shown in Figure 11 (labeled “post-case study”). 7 (44%) respondents selected “Excellent” when rating their understanding of pathophysiology, treatments and typical outcomes for gastric cancer and peptic ulcers. 7 (44%) respondents selected “Poor” when rating their understanding of risk factors, signs and symptoms, and diagnostic tools for gastric cancer and peptic ulcers. The reasons for an overall drop in knowledge confidence are unclear, especially as the case study scores were higher than on the first attempt. It may be that only students who felt they needed more review took the case study a second time. We did not have students complete this particular survey again after their 2nd attempt, so it is only speculation.

Though once the students had completed the Abdominal Pain Case Study they were invited to complete a second set of optional survey questions to assess their perceived level of understanding of the risk factors, pathogenesis, treatments, diagnostic tools, knowledge of vocabulary words (e.g. occult blood, hematemesis, melena), and possible complications of peptic ulcers (Figure 12). The majority of students agreed that this case study helped them understand the location of peptic ulcer pain, signs and symptoms as well as possible complications (82%), the main two risk factors of peptic ulcers, typical treatments, what occult blood is and how the fecal antigen test and barium x-rays can be used in the diagnosis process of peptic ulcers (73%), and the urea breath test, endoscopy diagnostic tests, and the specific vocabulary words hematemesis and melena (55-63%).

### Responses to Survey Questions: This case study helped me understand ____

<table>
<thead>
<tr>
<th>Survey Questions</th>
<th>0%</th>
<th>20%</th>
<th>40%</th>
<th>60%</th>
<th>80%</th>
<th>100%</th>
</tr>
</thead>
<tbody>
<tr>
<td>the two main risk factors for developing a peptic ulcer.</td>
<td></td>
<td>18%</td>
<td></td>
<td>73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the location of pain that can be experienced with a peptic ulcer.</td>
<td></td>
<td>9%</td>
<td>82%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>what occult blood is.</td>
<td></td>
<td>18%</td>
<td></td>
<td>73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the Urea Breath Test, a diagnostic tools of peptic ulcer disease.</td>
<td></td>
<td>27%</td>
<td></td>
<td>55%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the Fecal Antigen Test, a diagnostic tools of peptic ulcer disease.</td>
<td></td>
<td></td>
<td>73%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>endoscopy and how it can be used to diagnose peptic ulcers as well as esophageal or gastric cancer.</td>
<td></td>
<td>27%</td>
<td>55%</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>how barium x-ray tests can assist with diagnosis of diseases and disorders in the digestive tract.</td>
<td></td>
<td>27%</td>
<td></td>
<td>73%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the treatment of peptic ulcer disease.</td>
<td></td>
<td></td>
<td>73%</td>
<td></td>
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</tr>
<tr>
<td>the signs and symptoms of peptic ulcer disease.</td>
<td></td>
<td>9%</td>
<td></td>
<td>82%</td>
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<tr>
<td>possible complications of peptic ulcers.</td>
<td></td>
<td>9%</td>
<td></td>
<td>82%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>the difference between hematemesis and melena.</td>
<td></td>
<td>27%</td>
<td></td>
<td>64%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>how stress and smoking can be risk factors for developing peptic ulcer disease.</td>
<td></td>
<td>18%</td>
<td></td>
<td>73%</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 12. Student Satisfaction Survey - Completed After the Abdominal Pain Case Study. 2nd year nursing students rated the case study's abilities to promote learning of different parts of these topics. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
The results of the case study component survey are shown in Figure 13. This was the last case study and there were fewer participants than in the preceding case studies. In addition, if students had completed previous assignments, this case study was optional with the sole purpose of being used by students to make up for marks and/or help in their preparation for the final exam. This, as well as student fatigue, likely influenced the number and spectrum of participants taking part in this case study. 50-60% of students agreed that the various components of the case study (plastic models, x-ray) and should be used in the future. 58% of students thought it would help them remember various aspects of peptic ulcer disease and 67% of students found the case study engaging and/or fun.

In addition to the questions asked in Figure 12 and 13, students were able to fill in an optional comment box as well (Appendix, Table 3). Student comments are difficult to interpret overall, as case study material was covered in class and there was the complicating factor of reduced attendance. In addressing the comments, Question 9 did require critical thinking and problem solving from what was portrayed in the case study. Specifically, the students were asked to write down why the patient gained weight (due to over-eating as eating reduced pain). In addressing comments that the plastic models were confusing, it is true that the plastic stomach and small intestine models did have more (13) labels on them, compared to all of the previous models, meaning more patience would be required. The labels were clear, so it is likely that students were in a rush. And these were questions that required looking at the model in order to provide an answer. Overall, it is believed that students were fatigued by the end of term and therefore this case study will be modified or given more time in class in the future, to ensure all the students answer the model questions before rushing out the door.

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**Figure 13. Student Survey on Abdominal Pain Case Study Components.** 2nd year nursing students rated the usefulness of the various multimodal aspects of this case study. Possible ratings to each statement were: Strongly Agree, Agree, Somewhat Agree, Somewhat Disagree, Disagree, and Strongly Disagree.
E. Four 2nd Year Nursing Case Studies – Final Exam Question Analysis

After the final exam, question results were compared to see if students who completed each of the case studies had higher grades on related questions on the final exam. There were 4 osteoporosis and fracture questions, 5 heart disease questions, 1 peptic ulcer question, and 5 diabetes related questions on the final exam. Both Pearson correlational analysis and paired two-tail t-test analysis (results not shown) revealed that there were no significant correlations between scores of case studies and related final exam questions for case study participants and non-participants.

Looking more closely, there were only very weak correlations* found between the final exam questions Q3, Q8, and Q15, and the osteoporosis and fracture case study, the heart disease case study and the abdominal pain case study results respectfully. In the diabetes case study, scores of the 3 case study components (Images & Plastic Models, Insulin Video Quiz and the Diabetes Video Quiz) were separated for correlational analysis (and paired two-tail t-test analysis). The final exam diabetes related questions, Q10, Q12, and Q13 scores weakly correlated with scores for the insulin video and diabetes video components. The final exam peptic ulcer question, Q13 score having a very weak correlation with the Abdominal Pain Case study score. The total final exam scores very weakly correlated with scores of the osteoporosis and fracture case study, heart disease case study and diabetes case study images and plastic model component. As might be expected, the total final exam scores exhibited weak correlations* with final exam question score of Q3, Q6, Q7, Q8, Q11, Q13, and Q15 and medium strength** correlations with Q2, Q5, Q9, Q10, Q12, and Q14.

F. Heart Disease Case Study – for 3rd Year Human Kinetics Students

3rd year Human Kinetics (HK) students also cover cardiovascular disease in their pathophysiology course and were therefore given a similar heart disease case study as the 2nd year nursing students with some significant modifications. There were 19 questions and students were taken through the risk factors, signs, symptoms, and diagnostic tests associated with both peripheral artery disease and coronary artery disease. Possible complications and pathogenesis of angina pectoris, myocardial infarction, hypertension, congestive heart failure, nephrosclerosis, retinopathy, as well as ischemic and hemorrhagic strokes. The images included both a CT angiogram and a Doppler ultrasound image of peripheral artery disease (PAD) in the leg.

This class had two sections with 102 students in Section 001 and 99 students in Section 002. This case study was optional and one of several ways of earning points toward the final class grade. It was hoped that students would use this case study as they started studying for the final exam. Students could complete this case study regardless of whether they needed those points or not. They were allowed unlimited attempts and their highest score was counted.

Prior to going through the case study, students could complete the optional, ungraded, and confidential survey (Figure 14). In this survey, students rated their level of understanding of the risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology as well as typical treatments of hypertension, angina pectoris, and heart failure. This case study was given to the students after they had a class in this unit, so it was not surprising that “I Haven’t Learned Yet” was selected the least often in answer to these questions (1-6 (1-9%) students depending on the question). On average, most students felt they had room for improving their mastery of this course content in each area with only 3-7% (2-5) of respondents selecting “Excellent” in response to these questions.

When considering future improvements to the course, it was noted that prior to the case study, students had low confidence in their understanding of CHF risk factors and pathophysiology for hypertension, with 23 (34%) and 19 (28%) students selecting “Poor”, respectfully in answers to those two questions. This is not too surprising as these are complex topics to learn with confidence. On the other hand, students were most confident in their ability to identify risk factors for hypertension. It should be noted that class attendance for both sections is estimated to be approximately 60% on most days as many students chose to watch the class recordings instead. As attendance is not taken during class it is impossible to determine if there is any correlation between attendance and participation in this case study.
The Benefits of Multimodal Interactive Case Studies

**Figure 14.** Student Reflective Survey - Completed Before and After the Heart Diseases Case Study. Students rated their understanding of aspects of a) Hypertension, b) Angina Pectoris and c) Congestive Heart Failure (CHF). Possible answers to each question were: Excellent, Very Good, Good, Poor and I Haven't Learned Yet.
26 students opted to complete the case study a second time and completed the survey at the beginning again. This survey depicts how students were feeling after their first attempt on the case study and their responses are shown in Figure 14. It was found that the majority of respondents felt that they improved in the mastery of each topic after completing the case study. Between 27-46% (7-12) of respondents selected “Excellent” in response to these questions. Only 1-6 (4-23%) respondents selected “Poor” when rating their understanding of various aspects of cardiovascular disease.

In terms of time spent on the case study, there were 31 students that likely left the case study running on their computers unattended, clocking in times ranging from 1hr 59min to 483hr 4min. Without including those times, the average time for the students' first attempt was 25min 26sec and 8 min 9 sec for the second attempt.

The average score for the 68 respondents on Attempt 1 was 16.28/25 (65%) and the average score for the 26 respondents on Attempt 2 was 23.75/25 (95%). For the 26 students that completed the 2nd attempt, there was an average improvement of 6.26 points (25%) which was found to be statistically significant (with alpha=0.05). Results of paired t-tests between Attempt 1 and 2 scores found the t-statistic value to be -6.01 and the t-critical value to be 2.06 (and the null hypothesis was rejected). 9 Students completed the case study a 3rd time and had an average score of 24.80/25 (99%).

G. 3rd Year HK Heart Disease Case Study – Final Exam Question Analysis

There were 16 heart disease related questions on the final exam. Both Pearson correlational analysis and paired two-tail t-test analysis (results not shown) revealed no significant correlations between scores of the heart disease case study (or case study participation) and related final exam questions. Very weak correlations* were found between final exam questions, Q4, Q5, Q9, Q26, Q27, Q28, and Q50, and the Heart Disease case study scores. Not surprisingly, weak* to moderate** correlations were found between many of the heart disease final exam questions and the total final exam score (Q2**, Q4*, Q5**, Q8**, Q13*, Q15**, Q16*, Q26**, Q27**, Q28*, Q40**, Q50**, Q63*).

Conclusions

We found that in both 2nd year Nursing Pathophysiology and 3rd year Human Kinetics Pathophysiology courses, students reported that the interactive case studies were beneficial to their learning. Most students stated that they enjoyed the multimodal and interactive components of the case studies (pictures, videos, tactile and hands-on, and electronic). Students appreciated the time flexibility, the opportunities to repeat the case studies and reflect on their knowledge, as well as visualize real life situations. Students cited the case studies as engaging, fun, and a good way to parcel and help remember newly gained knowledge. The majority of students also stated that the case studies should be used in the future.

As expected, each student found different modalities of the case study the most helpful (e.g. plastic models, video clips, video quizzes, x-rays, images, personal stories, interactive webpages, and instrument read-outs). It was noted that student ratings of their understanding increased in all of the various aspects of each disease and disorder with every attempt they took of the case study with the exception of a few topics in the final peptic ulcer case study. The majority of students stated that the case studies helped them understand each aspect of the diseases and disorders covered (e.g. risk factors, signs and symptoms, diagnostic tools, treatments, pathophysiology and typical outcomes). Student comments stated that participants also valued the metacognitive pieces embedded in each case study, and found it allowed for reflection on what they knew well and what they needed to review.

We found only very weak positive correlations between case study scores (and case study participation) and the scores on related questions in the final exams. It is unclear if these weak correlations are due to the case studies themselves, or if any converse effects would have occurred if they were not used. It may be that students who completed the case studies scored better on the final exam than they would have without participating in the case studies. It may also be that the case studies helped in a way that any additional Q&A practice would help when studying. Therefore, students that didn't participate in the case studies may have used other course resources to achieve the same benefit. Moreover, it may be that the case studies helped develop critical thinking, problem solving, and overall question answering skills, in addition to the learning and memory of the content – skills that may not have been tested for on the final exam. The final exam questions used in this current study were completely multiple choice. Further studies would need to be done to determine exactly what benefit the case studies may have on critical thinking, problem solving, confidence and motivation.

Another limitation of the study is that it was not possible to readily determine which of the four case studies was better in the eyes of the 2nd year nursing students as the number of survey participants for each case study decreased during the term.

Future considerations for research include creating case study questions in the final exam to encourage higher order thinking, as was done by successfully by Smee and Cooke (2018).
Acknowledgments
We would like to thank all of the 2nd and 3rd year students who volunteered their time to partake in these surveys.
We would also thank Natasha Pestonji-Dixon for assisting with the delivery of surveys and collection of anonymous survey results.
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About the Authors
Zoë Soon is an Associate Professor of Teaching in the Dept. of Biology, IKB Faculty of Science at the University of British Columbia Okanagan. She would like to respectfully acknowledge that UBCO is located on the traditional, ancestral, and unceded lands of the Syilx (see-ilk) Peoples. She and her family are very grateful to work, live and go to school in these beautiful lands. She teaches Human Anatomy and Physiology, Pathophysiology, Motor Development, Motor Behaviour, and Human Infectious Diseases.
Megan Lauridsen is a recent B.H.K graduate. At the time of this study, Megan was a 4th year undergraduate UBCO research student who assisted with this study during her capstone research project course.

Literature cited


continued on next page
# APPENDIX

## Student Suggestions:

<table>
<thead>
<tr>
<th>Two students</th>
<th>I think it would be more helpful if it gave immediate feedback after each question. Also some of the content did not align with the course. Also, I enjoyed it.</th>
</tr>
</thead>
<tbody>
<tr>
<td>One student</td>
<td>I found it distracting and interruptive to the methods of study that I prefer. The pictures took up too much space and as I scrolled back and forth from the pictures to the answers I often got distracted between what I was looking at and what I was looking for. Too much going on.</td>
</tr>
<tr>
<td>Three students</td>
<td>It should be shorter</td>
</tr>
<tr>
<td>One student</td>
<td>I found I had to cheat (Google) to get the answers. <em>(The case studies were open book, so I wouldn’t consider this cheating.)</em></td>
</tr>
</tbody>
</table>

## Positive Comments:

| Two students | engaging and fun                                                                                                               |
| Seven students | i like visual learning so having diagrams helped me                                                                 |
| One student  | This case study was well done, but it is not my personal preferred learning style                                               |
| Two students | It was helpful because it allowed a chance to test my knowledge.                                                                    |
| One student  | I didn’t have any of the answers in front of me so it is a little hard to tell if I got them correct, or if I was correct in my thinking. I think it would be awesome if you could answer a question and then find out if you’re right or wrong immediately after and then move onto the next question. |
| One student  | interactive and engaging                                                                                                       |
| One student  | I really enjoyed this because we have not yet done a case study yet in Pathophysiology and it was a different way of learning about this subject. |
| One student  | I found the case study useful as it forces you to think about the situation and apply your learning.                             |
| Two students | Good overall and it was well done                                                                                               |
| One student  | I genuinely appreciate how different learning style questions were incorporated in the questions. As a visual learner myself, I enjoyed doing questions involving diagrams. Thank you! |
| One student  | This case study was very helpful in understanding the different learning concepts, as it allowed for critical thinking and analysis of the patient scenario. |
| One student  | I really enjoy getting more information about a situation between questions. It really helps me simplify the information into smaller amount. |
| One student  | I liked the case study background                                                                                            |
| One student  | It helped me learn.                                                                                                             |
| One student  | I find this is helpful to apply learning to real world scenarios.                                                               |
| One student  | Case study was helpful and easy to answer.                                                                                    |
| One student  | I found the case study helpful and enjoyed the interactive part of the learning.                                                |
| One student  | I believe that the diversity in the formatting of the questions truly helped test my understanding, rather than my ability to memorize the learning concepts. |
| One student  | I found that this case study was helpful because the format really tested by critical thinking skills. I liked having the second retry option because it gave me the opportunity to do the test without any preparation in the beginning. This allowed me to see where I was in my current understanding. Afterwards I felt like I really improved my understanding because I was then focused on the parts that I needed to work on. |
| One student  | Very nice to see a diverse method of knowledge dissemination! I really appreciate the formatting, and it extremely clear that this case study is well-developed. It’s very impressive! Thank you! |

**Table 1.** Student Comments (n = 34 respondents) Written in Case Study Component Survey Completed After the Osteoporosis and Fracture Case Study.
The Benefits of Multimodal Interactive Case Studies

It aided in my understanding of diseases and causes
It helped me to think through the knowledge taught in lecture.
I did not get a chance to look at any models so I found the case study somewhat confusing.
Some of the words we have no learned, so some googling was requires
I don’t remember seeing plastic models in class
I think it will help me remember for the exam. I didn’t get time to look at the models in class but the pictures helped. I like that it adds a story to the learning. I would prefer immediate feedback about the answers instead of waiting until the end.
Maybe have less true/false questions, I didn’t find them as helpful as the other questions.
You are required to look up the answers to many questions which helps with active learning and hopefully recall.
Some of the content wasn’t found in the lecture notes, but I was able to find it in the textbook.
This case study was helpful because were able to complete it multiple times and try again if we didn’t get it right the first time. It was helpful that it told us why we were wrong instead of just saying we were wrong.
Engaging
I wish I could answer a question and then see if I was right afterwards. That would really help.
I am a very visual person so this case study helped me a lot
This was very helpful. Thanks
I found it to be more advanced than what we have learned in this course and was quite difficult to understand
pictures helped me learn differences
it’s helpful to be able to test yourself to really see what you do and do not understand then you can focus on what you need to cover more in depth
It was helpful to put in my knowledge with a real life situation
a lot more helpful than the regular participation bonus challenges
It was helpful in showing models and images that helped me visualize the information and think through the questions to find the answer.
put in real life examples
I like how it was a different way of learning because I am a more interactive learner, not visual (like in class)
I like case studies because they are interactive and allow me to utilize other forms of learning like kinesthetic for example (not just visual)

I found that the questions related to what we learned in class and that it actually tested my knowledge.
It was helpful because it highlighted the both specific symptoms and broader effects. Also helped me realize that I need to study more to get a better understanding
It was helpful to learn about the disorders associated with the heart and hypertension incrementally through stages, as well as to have the models and their descriptions was very helpful in the skill testing knowledge questions asked about the material afterwards
Pictures are helpful for learning + additional review of material covered in lecture
it was helpful in compartmentalizing the different information by presenting it in a nice order!
being able to read out a full scenario helped to understand
Going into it blind, and having not studied the material at all gave me a good measuring stick about my base knowledge, and shows me what I have committed to memory and what I need to brush up on and review in greater depth
I find I get too distracted with the various options to look at and just start guessing the answers instead of focusing on the questions
plastic model used was confusing
I think this case study would be more effective if there was a background story and more detailed patient information. I think it utilizes more specific critical thinking skills instead of having to check off the list of S&S that we go over in class.
Some of the questions were worded/presented in a confusing way.
too much going on for me to stay interested in regards to a “quiz”
I would have found it more helpful to have more hints in the question to figure out the answers, and then be able to see the right answer immediately!

it was helpful as it incorporated visual material as well, I also find it helpful to apply it to scenarios
not 100% a refection of the current course
This was really helpful, it helped review the material and helped indicate what I still need to do more review on. The pictures and explanations gave a good visual and assistances in answering the question
As of filling out this survey I don’t know what i got correct or incorrect, so I'm not sure what I think I might know vs what i don't know for sure.
I like a different approach to the learning
I think this should be utilized more often!
I think you should incorporate case studies into class more often!

Table 2. Student Comments (n = 42 respondents) Written in Case Study Component Survey Completed After the Heart Disease Case Study.
<table>
<thead>
<tr>
<th>Comment</th>
</tr>
</thead>
<tbody>
<tr>
<td>I felt that question 9 was non applicable to the content covered in class. I also did not have time to look at the models in class and we didn’t really go over that content so it was not a good way to reinforce learning (because we didn’t learn it in the first place)</td>
</tr>
<tr>
<td>It helped me remember the information by applying it.</td>
</tr>
<tr>
<td>I didn’t find this case study very helpful. The models were a little confusing and didn’t help with my learning.</td>
</tr>
<tr>
<td>It provided different ways of learning (i.e. looking at models, reading the case study, providing extra information, videos).</td>
</tr>
<tr>
<td>The questions in this case study were a bit like a guessing game for me, which means I need to brush up on and reinforce the content from this lesson.</td>
</tr>
<tr>
<td>The models did not fit on my screen and I was scrolling back and forth too much to recall what I was looking at/answering</td>
</tr>
<tr>
<td>I had a lot of trouble identifying specific stages of peptic ulcers on the stomach model</td>
</tr>
<tr>
<td>These case study quizzes are very helpful</td>
</tr>
<tr>
<td>I did not find the stomach diagrams useful at all as I didn’t know what I was looking at. I also wish answers were given after each question so we know right away what we were right or wrong about while it is still fresh in our minds.</td>
</tr>
</tbody>
</table>

**Table 3.** Student Comments (*n* = 10 respondents) Written in Case Study Component Survey Completed After the Abdominal Pain Case Study
Never Heard That Before! Bioscience Knowledge Retention in Undergraduate Nursing Education

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Abstract
Human anatomy and physiology are considered foundational courses in medical, allied health, and nursing disciplines and serve as prerequisites for future theory courses and nursing clinicals. Numerous studies have demonstrated the difficulty for medical and allied health students to acquire, transfer, retain, and apply knowledge from these courses in subsequent years of their programs. However, most knowledge retention studies of anatomy and physiology have been carried out with a focus on medical and allied health students and have rarely been assessed in nursing students. In addition, most studies of interventions in anatomy and physiology have emphasized factors affecting knowledge acquisition in the first year of nursing, and little is known about knowledge retention and application during subsequent years of nursing. This review highlights the current status of knowledge retention in nursing education, identifies potential gaps, and discusses interventional strategies to bridge the gap between the classroom and future theory courses and nursing clinicals. https://doi.org/10.21692/haps.2021.009

Key words: anatomy and physiology, knowledge retention, nursing, knowledge application, clinical application

Background
Human anatomy and physiology are considered cornerstones of any health-related profession and serve as a pre-requisite for clinical placements (Estai and Bunt 2016, McVicar et al. 2014, 2015). A strong knowledge base in these courses is crucial for nursing students to become successful practitioners after graduation (Andersson and Edberg 2010, McVicar et al. 2014, 2015). On the other hand, poor education and a lack of sufficient bioscience knowledge can result in nursing errors leading to compromised patient care and safety as well as adverse clinical outcomes (Davis 2010).

Nursing students view anatomy and physiology courses as the most difficult, content-heavy, stressful, and anxiety-provoking courses of their nursing programs (Craft et al. 2017, McVicar et al. 2015). Numerous studies have suggested that students experience great difficulty in transferring the fundamental anatomical and physiological knowledge that they gain in the first year of their programs to future theory/clinical practice (Friedel and Treagust 2005, Gunay and Kilinc 2018, Narnaware 2021, Narnaware and Neumeier 2020, Narnaware and Neumeier 2021b, Narnaware et al. 2021). A gradual loss of knowledge associated with these courses is also evident among some nursing professionals and educators (Friedel and Treagust 2005, McVicar et al. 2014).

Anatomical and physiological knowledge retention in students enrolled in nursing programs has not been assessed as extensively as that in students enrolled in medical and allied health studies and, therefore, little is known about its acquisition, transfer, and application to future theory/clinical practice (Gunay and Kilinc 2018, Narnaware 2021, Narnaware and Neumeier 2020). Any studies that have been conducted on this topic are either focused on first-year nursing students (McVicar et al. 2014, 2015) or on nurses in entry-level in nursing programs (Davis 2010, McVicar et al. 2014, 2015). In addition, most of these studies have assessed knowledge acquisition and transfer pertaining to limited body systems (Diaz-Mancha et al. 2016), so systemic, organ-by-organ anatomical knowledge transfer, and its application to gross anatomy remains to be assessed. Moreover, little is known about potential gaps and factors affecting knowledge transfer and its application to future nursing courses/clinical practice.

Therefore, the knowledge transfer, retention, and application of these courses over time in the nursing curriculum remains to be assessed. The purpose of this paper is to overview available knowledge retention studies and highlight factors affecting knowledge retention in nursing education. An additional goal is to identify potential gaps so that robust interventional strategies can be developed to bridge the gap between the classroom and future theory and clinical courses in nursing.

Knowledge Retention Studies in Undergraduate Nursing Education
Teaching and learning of anatomy and physiology in nursing programs can be viewed as problematic (Craft et al 2017, Friedel and Treagust 2005, Narnaware 2021, Narnaware et al. 2021). The nursing student’s perception of these courses is that they are challenging, anxiety-provoking, difficult, and add a significant stress during their first year of nursing studies (Davis 2010; Craft et al. 2017, McVicar et al. 2015). The student’s
ability to acquire, transfer, retain, and apply aspects of anatomical and physiological knowledge to his or her second-year clinical practicum and future years of undergraduate nursing is of concern, as it is for medical and allied health students and professionals (Craft et al. 2017).

Reports related to European nurses revealed that only 9.5% received extensive bioscience education during their nursing program and 40.5% of experienced registered nurses felt that bioscience content failed to help them accomplish their roles as nurses (Davis 2010). In a recent study, Gunay and Kilinc (2018) reported that many graduate nurses felt that there was either inadequate bioscience content in their nursing programs or excessive theoretical knowledge in the first year of nursing.

On the other hand, surgical nurses in the United Kingdom (UK) understood the crucial importance of anatomy and physiology, but were unable to correlate physiological changes with their patients’ conditions (McVicar et al. 2014) or adequately integrate bioscience knowledge into a clinical setting (Craft et al. 2017, Friedel and Treagust 2005). Many were frustrated with their inability to put bioscience knowledge into practice and perceived it as detrimental to overall patient care (Andersson and Edberg 2010, Davis 2010). Similar concerns were expressed by nurses trained in Australia, New Zealand and Turkey (Friedel and Treagust 2005, Gunay and Kilinc 2018).

For the past two decades, due to the introduction of a myriad of novel teaching modules, many medical and allied health programs have shifted away from the use of cadavers and prostectons in favor of the newer technologies. However, the use of these newer technologies in nursing programs, particularly in the first year of nursing, and evaluation of their impact on long-term knowledge retention are rare, despite a leaning toward their adoption in nursing education (Bianchi et al. 2020, Narnaware and Neumeier 2021a, Souza et al. 2016). Moreover, the ability of these technologies to reduce cognitive load, lower exam stress and anxiety, and reduce behavioral responses that are associated with the use of cadaver dissection has not been assessed (Bianchi et al. 2020).

Although anatomy and physiology are perceived as inseparable subjects, and knowledge of these subjects is invaluable to effective clinical practice (Andersson and Edberg 2010, Culyer et al. 2018), research has described the existence of a gap between theory and practice in these crucially important subjects in the medical and allied-health curricula (McFee et al. 2018). This gap has rarely been assessed in nursing education.

As far as nursing curricula are concerned, most knowledge retention studies have focused more on anatomical knowledge retention, alone, rather than physiological knowledge retention. The reported nursing education-related studies in physiological knowledge retention have either focused on the impact of various active learning modalities (Collins et al. 2021, Majeed 2014), labs (Metz and Metz 2021), simulation (Alt-Gehrman 2019), or kinesthetic learning (Wagner 2014) on knowledge acquisition and retention (Craft et al. 2017, Culyer et al., 2018; Wagner, 2014) or academic performance (McVicar et al. 2015) in first year nursing students, or its transfer and application in intensive care units a year after students’ graduation (Aari et al. 2004, Andersson and Edberg 2010). This suggests that there is a potential gap in knowledge transfer/loss, retention and application in subsequent years of nursing, but the studies needed to address this issue have not been carried out.

Most of the retention studies in nursing education have focused on the impact of the limiting factors affecting physiological knowledge acquisition/retention in first year (Dante et al. 2011, Pitt et al. 2012). Moreover, application of interventional strategies to improve knowledge acquisition and retention in physiology by first-year nursing students are limited compared to those that have been applied in anatomy (McVicar et al. 2015). Finally, these retention studies have reported physiology knowledge retention assessment in only a limited number of organ systems (Aari et al. 2004, Wagner 2014). Therefore, the assessment of base-level knowledge retention in overall organ system physiology during the first year of nursing and its transfer/loss, retention and application to subsequent years of nursing curricula warrants further exploration.

Factors Affecting Knowledge Retention Studies in Nursing Education

Like other medical and allied health care professions, nursing education continues to evolve worldwide to support professional and clinical roles and adequate anatomical and physiological knowledge is perceived as pivotal to allowing nursing students to become highly successful future nursing practitioners (Andersson and Edberg 2010, McVicar et al. 2014, 2015). At most educational institutions, these courses are being taught by employing a traditional didactic, passive teaching and learning approach (Narnaware and Neumeier 2020, Wagner 2014). It is limited to plastic models, mannequins, human skeletons, simulation, animal dissection, and the use of textbooks (Narnaware and Neumeier 2020). However, this teaching approach, coupled with the limited use of cadavers and prostectons in nursing, has prevented nursing students from gaining an in-depth knowledge of the structure of the human body. It has also failed to adequately prepare them to function clinically with empathy (Washmuth et al. 2019). The use of modern teaching technologies such as computer-generated three-dimensional (3-D) images and social media as well as cutting-edge teaching technologies such as a three-dimensional (3-D) virtual human cadaver (e.g., the Anatomage Table; www.anatomage.com), may also affect student knowledge acquisition and retention (Attardi et al. 2016, Estai and Bunt 2016, Narnaware and Neumeier 2021a, McVicar et al. 2014, 2015).

continued on next page
Additional factors that have been shown to impact knowledge retention in nursing education include, but are not limited to, insufficient instructional time allotted to these courses (Al-Modhefer and Roe, 2009, Narnaware and Neumeier 2020, Narnaware 2021, Snelling et al. 2010), demographic factors (Dante et al. 2011, McVicar et al. 2014), students’ prior knowledge of biology, and/or to their entry-level exam scores (McVicar et al. 2015). Their knowledge acquisition and retention may be impacted by course delivery methods and teaching strategies (Davies et al. 2000), including an excessive reliance on self-directed learning (McVicar et al. 2014, 2015), reduced use of laboratory and clinical environments (Günay and Kılınç 2018), and on the individual instructor’s personal qualities, knowledge and expertise in these courses (Friedel and Tregust 2005). Finally, completely replacing cadaver and prosection use with newer technologies, particularly in the first year of nursing, could potentially have a negative impact on the student’s long-term knowledge acquisition and retention (Washmuth et al. 2019).

Pedagogical Approaches to Improve Knowledge Retention in Nursing Education

The benefits of a robust interventional strategy to bridge the gap between first-year theory and clinical practice in medical and allied health students are well-documented (Manyama et al. 2016, Rutty et al. 2019). However, little is known about incorporating these strategies into nursing curricula (Davies et al. 2000, Narnaware 2021). Available strategies that have been shown to effectively to enhance long-term knowledge retention by nursing students are content reinforcement, retrieval of anatomical knowledge, and kinesthetic and active learning (Esati and Bunt 2016, McVicar et al. 2015, Narnaware et al. 2020). Also, visualization through body images (Narnaware 2018, Rutty et al. 2019), peer tutoring (Alfaro et al. 2019), and mentoring programs have been shown to be beneficial in knowledge acquisition (McVicar et al. 2014).

Various teaching and learning modalities include introducing computer-generated 3-D images, or the use of a virtual human cadaver to provide an experience similar to that obtained with a real human cadaver while helping to reduce anxiety, stress, and behavioral responses usually associated with cadaveric dissection (Bianchi et al. 2020, Narnaware and Neumeier 2021a, Washmuth et al. 2019). Also, online learning platforms such as Kahoot! quizzes (www.kahoot.com), in-class activities, group discussion, classroom presentations by students, and directing students to more online activities outside the classroom (Narnaware 2021, Narnaware & Chahal 2019, Rutty et al. 2019) and various evidence-based teaching strategies (Culyer et al. 2018) could be hugely beneficial for knowledge and long-term memory retention.

Other pedagogical approaches include allocating more teaching hours for theory classes, the introduction of labs and exams with more textbook images (Narnaware 2018), and content reinforcement (repeated knowledge assessment) (Narnaware et al. 2020). Similarly, problem-based learning (PBL) and case-based learning (CBL) with cooperative small group work and role-playing could be effective (Culyer et al. 2018). Lastly, the introduction of anatomy and physiology refresher courses at the beginning of each academic year, and access to first-year anatomy and physiology course materials could help with application and long-term memory retention. Therefore, blended, multimodal, and system-based pedagogical approaches are suggested as they have been shown to be more effective for nursing students (Estail and Bunt 2016, Souza et al. 2016).

Conclusion and Future Directions

The present review provides an initial understanding of knowledge retention of anatomy and physiology by nursing students and potential factors affecting their application to nursing education. Once areas of strengths and weaknesses in anatomical and physiological knowledge retention are identified, interventions that address those issues can be evaluated. As these findings may not be generalizable to other populations, it would be useful to conduct future studies at different nursing institutions to validate their findings in a broader context.

The perceived notion that knowledge attrition may vary significantly for the body’s major organ systems would be of interest for other nursing programs and health sciences educators, as collecting this base level data could inform targeted educational interventions. The data collected will create interactive learning modules to close the gap between theory and clinical practice. The challenge for undergraduate nursing institutions committed to student success is to develop strategies aimed at addressing factors that are appropriate to specific contexts and student cohorts. While nursing educators focus on long-term knowledge retention and its application, the current trends in nursing, such as shifting from didactic, passive learning to active learning with the adoption of newer teaching technologies that foster student engagement, social interaction and communication skill development, must be kept in mind when designing nursing curricula to produce knowledgeable, confident and competent nurse practitioners (Alt-Gerhrman et al. 2019).

About the Author

Dr. Raj Narnaware is an Assistant Professor in the Department of Human Health & Sciences, Faculty of Nursing at MacEwan University, Edmonton, Alberta. He teaches human anatomy and physiology to the Bachelor of Science in Nursing (BScN) and Psychiatric Nursing (BPN) students. As a researcher, he is involved in several Scholarship of Teaching and Learning (SoTL) projects that focus on the efficacies of modern, cutting-edge teaching technologies to improve student knowledge.
In addition, he is also involved in assessing anatomical and physiological knowledge acquisition in the first year of nursing and its transfer and application to future nursing courses and clinical experiences by developing robust interventional strategies to bridge the knowledge gap between theory and clinical.

References


Metabolism and Nutrition: Integration of Concepts in a Holistic Approach to Teaching Metabolism

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Abstract
Metabolism and nutrition are interrelated factors of human physiology, so much so that they cannot be thought about independently of each other. Yet, the way that either nutrition or metabolism is often discussed leads to questions about how well this interrelationship is understood. This paper will discuss how clarifying terminology and incorporating the interrelationship between metabolism and nutrition in instruction can combat many of the biases and misconceptions that get perpetuated to students. This should allow students to be better prepared for their future roles in healthcare.

https://doi.org/10.21692/haps.2021.026

Key words: nutrition, metabolism, anatomy and physiology, misconceptions, energy balance

Introduction
Teaching the concepts of nutrition and metabolism in an anatomy and physiology course can be fraught with difficulties for a number of reasons. One of the most frequently encountered difficulties comes from a lack of awareness of key terms as they are used scientifically versus what they have become through common expression. Combined with inherent and societal biases related to the discussion of nutrition and metabolism, this can limit the overall educational experience. These are issues that must be addressed, as a lack of awareness leads to the perpetuation of many of the common myths and misconceptions held by students and faculty alike, some of which may then get reinforced via perpetuation by textbook editors and authors. This is of concern given that the concepts of nutrition and metabolism have become cornerstones of lifestyle and behavioral modifications (i.e., diet and exercise regimens) related to the prevention and treatment of many common non-communicable diseases, such as cardiovascular disease, obesity and cancer, that students will encounter in their future careers in healthcare (Booth et al. 2000, Clark 2012, Smith et al. 2018, Wolowczuk et al. 2008).

An important principle of treatment is based on how nutrition can directly and indirectly impact inflammation, in turn impacting metabolic functions and the homeostatic regulation of the body (Kremmyda et al. 2011, Smith et al. 2018, Wolowczuk et al. 2008). This is an issue that requires the topic of nutrition and metabolism and its link to inflammatory responses to be properly understood. An additional challenge for instructors is that many students will arrive with some preconceived notions about nutrition gained from any of numerous books available at their local bookstore or founded on ideological and dogmatic practices, rather than an understanding of the physiological principles underlying metabolism and metabolic processes.

This selective attention, without gaining a proper perspective about metabolism and nutrition presents a problem of conformational bias. This bias may limit the ability of students to gain a full understanding of what nutrition and metabolism actually are, or how a particular concept directly impacts another, e.g., interaction of body composition with nutrition and metabolism, interaction of metabolism with overall health and wellness (Booth et al. 2000, Clark 2012, Smith et al. 2018). The end result of this can lead to bias regarding recommendations of exercise or nutrition and diet modifications to future patients (Hosseini et al. 2008, McCullough and Willett 2007). Moreover, this lack of understanding may limit their ability to provide a rationale for why, or more often why not, a person should take dietary supplements.(Clark 2019, Dodd et al. 2020, Fallah et al. 2020). Finally, it may lead many to not understand that, while acutely changing nutrition and physical activity will result in changes to body composition and health status, the same change may not be sustained for a host of physiological and psychological reasons (Hall 2008, 2013, Thomas et al. 2013).

Even more problematic for students is the concurrent stress they face within their social networks. Once a family member or friend knows that the student is studying human physiology, they may ask for the student's professional opinion on the best diet plan, exercise regimen, or strategy to speed up their metabolism, so as to drop weight and get healthy. This leads to the purpose of the current review addressing why we should teach the interconnectedness of nutrition and metabolism. Integrating these concepts when teaching human anatomy and physiology may help to dispel myths and...
misconceptions, limit the totality of conformational bias that students might hold, and lead students to be more prepared to function as the healthcare professional they are training to become.

**Metabolism**

*Key Terms*

“You keep using that word, but I don’t think it means what you think it means” (The Princess Bride). As with many topics in anatomy and physiology, not to mention science as a whole, the terms that we use may not match the commonly held belief for what that term means. A key factor in the battle against the myths and misconceptions of nutrition and metabolism is to have students grasp what we mean when we discuss these terms.

When discussing metabolism there is one misconception that must be nullified before a serious discussion can be had. That misconception revolves around the question at the heart of this review: *What is metabolism?* If we were to go from how textbooks define the concept then we are simply discussing the anabolism (building up) or catabolism (breaking apart) of macromolecules. If we were to go from the common expression that many students hold, it is the amount of energy used in a day. However, when we look at the concept in more depth, a much more descriptive definition becomes evident. Metabolism should be seen as the sum of all chemical reactions that are involved in the cells and tissues of the body necessary to maintain, or regain, homeostasis. From this perspective we can further delve into the various types of chemical reactions linked to metabolism that students tend to have difficulty grasping (Table 1).

<table>
<thead>
<tr>
<th>Chemical Reaction</th>
<th>Definition/Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerobic Metabolism</td>
<td>Chemical reactions that require the presence of oxygen, typically associated with mitochondria metabolism for regenerating ATP</td>
</tr>
<tr>
<td>Anaerobic Metabolism</td>
<td>Chemical reactions that do not require the presence of oxygen, typically associated with cytoplasm metabolism for regenerating ATP</td>
</tr>
<tr>
<td>Metabolite</td>
<td>Any molecule or elemental atom involved in the metabolic pathway</td>
</tr>
<tr>
<td>Product</td>
<td>Molecule or elemental atom that is formed from the metabolic pathway and is used in the next step of the metabolic pathway</td>
</tr>
<tr>
<td>Byproduct</td>
<td>Molecule or elemental atom that is formed in the metabolic pathway but is not used in the metabolic pathway that forms it</td>
</tr>
<tr>
<td>Anabolic</td>
<td>Chemical reaction that leads to the production of polymer macromolecule from monomer and dimer subunits</td>
</tr>
<tr>
<td>Catabolic</td>
<td>Chemical reaction that leads to the production of monomers and dimers subunits from their polymer macromolecule</td>
</tr>
<tr>
<td>Oxidation</td>
<td>Chemical reaction that leads to the loss of an electron (or Hydrogen ion) from the metabolite in the formation of the product or byproduct</td>
</tr>
<tr>
<td>Reduction</td>
<td>Chemical reaction that leads to the gain of an electron (or Hydrogen ion) by the metabolite in the formation of the product or byproduct</td>
</tr>
<tr>
<td>Kination</td>
<td>Chemical reaction that involves the movement of a phosphate group onto a molecule that either activates or inactivates the molecule</td>
</tr>
<tr>
<td>Isomerization</td>
<td>Chemical reaction that changes the shape of the molecule, leading to changes in molecule function without changing atomic composition</td>
</tr>
<tr>
<td>Combustion</td>
<td>Chemical Reaction of a hydrocarbon (carbohydrate) resulting in the formation of water and carbon dioxide as products or byproducts</td>
</tr>
<tr>
<td>Cis-</td>
<td>Molecule shape where the functional groups or atoms are on the same side of the molecule axis</td>
</tr>
<tr>
<td>Trans-</td>
<td>Molecule shape where the functional groups or atoms are on opposite sides of the molecule axis</td>
</tr>
<tr>
<td>Functional Group</td>
<td>Group of atoms within a molecule that determine action within metabolic pathways</td>
</tr>
</tbody>
</table>

*Table 1. Chemical reactions and terms associated with human metabolism.*
One of the types of reaction that students find difficult is the reduction and oxidation (redox) reaction (Table 1). More importantly, students struggle with the concept of reactive oxidative species (ROS), or free radicals, that might form within redox reactions in the cells of the body as well as the antioxidants that are meant to temporarily bind and neutralize them. The ROS molecules form when redox reactions leave a molecule with an unpaired valence shell electron. While these molecules can form in many of the metabolic pathways, they are traditionally seen as forming in energetic pathways and mistakenly linked to having oxygen as part of their structure given that oxidative is seen in the name. ROS molecules may involve an oxygen molecule, but are not strictly about oxygen, as the principal elements that may oxidize are nitrogen and oxygen while the primary reducing agent is the hydrogen atom (Lobo et al. 2010).

These ROS molecules are linked with a host of metabolic issues and diseases and have led to speculation that people must supplement their diet with antioxidants (Clark 2019, Dodd et al. 2020, Fallah et al. 2020, Kerkick et al. 2018, Mason et al. 2020, Munoz et al. 2010). However, when one is healthy (low oxidative stress), cellular mitochondria are forming various antioxidant compounds at a high enough rate to counter ROS formation (Fallah et al. 2020, Mason et al. 2020). This suggests that healthy people may not benefit from consuming excessive amounts of antioxidants and that excessive consumption may even cause harm by downregulating intrinsic antioxidant production (Clark 2019, Mason et al. 2020, Munoz et al. 2010).

Another misconception that must be addressed is the concept of calories or Calories. The misconception here is more about what these terms don't mean rather than what they do mean and can lead to a poor understanding as it relates to the nutrition and health. First, notwithstanding how we might hear people talk about calories (Calories), a calorie (Calorie) cannot be burned, simply because the calorie is a unit of heat. As classically defined, a calorie is the amount of heat necessary to raise 1 gram (or mL) of water 1°C Centigrade, while on the other hand, a Calorie is 1000 calories, or 1 kcal, and is the amount of heat necessary to raise 1 kg (or L) of water 1°C Centigrade. We typically discuss Calories when discussing energetics and human metabolism. In examining energy requirements for living, we use the Calorie to examine the heat being emitted by the combustion reactions (converting a hydrocarbon to carbon dioxide and water) necessary for ATP regeneration, but it must be reiterated that Calories are not being burned. It is much better to discuss Calories as being expended, not burned.

**Metabolic rates, energy expenditure and whole-body metabolism**

This idea of expending Calories in activity and metabolism leads us to another concept that is rife for myths and misconceptions: metabolic rate. In general, metabolic rates are discussed based on the energy expenditure necessary for any activity, whether that activity comes from physical activity and exercise or just daily living. (Kenny et al. 2017, Lam and Ravussin 2016, Ramirez-Zea 2005). While we commonly discuss metabolic rate based on energy expenditure, it is important to remember that metabolic rate is simply the measure of amount of metabolism completed per unit time and not necessarily the amount of energy being expended.

Focusing on the concept of energy expenditure, there are differences in metabolic rates based on the reference for point of time. The unit of time used in determination of rate is going to vary based on the purpose of the measuring metabolic rate for a person. If looking at metabolism stemming from exercise, our unit time will be based on the hour or the minute, e.g., expenditure per kg per hour (kJ/hr), as is typically seen with VO2 values. However, most metabolic rates that are referenced are indicated based on the daily expenditure (Cal/day), a value that represents the amount of energy that is being released from the various metabolic reactions and mechanical actions that are necessary to perform all activities for that day. In using the daily reference, we discuss the total energy expenditure (TEE) for the individual, in which TEE is the reference of the combination of resting energy expenditure (REE), active energy expenditure (AEE) and thermic effect of food (TEF), simplified to the equation: TEE = REE + AEE + TEF. Unfortunately, it is very difficult to obtain a true measure of energetic cost for any activity or for the sum total of all metabolic processes (Kenny et al, 2017; Lam and Ravussin 2016, Ramirez-Zea 2005). Hence, it is usually estimated using a variety of regression equations of Calories expended (Table 2) or indirect measurement of heat production (ACSM 2006, Kenny et al. 2017, Lam and Ravussin 2016, Ramirez-Zea 2005). Within the methods for determining an estimated daily energy expenditure, a change in terms comes into the fold. Instead of TEE, the discussion now focuses on basal metabolic rate (BMR).

There are a host of equations that have been shown to be valid for estimating a person’s BMR (Table 2). To determine either the estimated BMR or the TEE, a variety of factors come into play. We can divide these factors into modifiable (those factors over which we have influence, i.e., level and duration of habitual activity, health status, body mass and composition, diet) and non-modifiable (factors that we cannot control, i.e., age, gender, ethnicity, height) (Henry 2007, Kenny et al. 2017, Ramirez-Zea 2005). Within the modifiable factors, there is an antiquated thought that increasing fat-free mass (skeletal muscle) elevates BMR. However, this thought may be open to reconsideration as adipose tissue has been shown to be metabolically very active and is not simply an inert storage tissue (Clark 2012, Hall 2008, Hellerstein 1999, Jensen 2002). One misconception that many students have related to BMR is that there are individuals with a fast metabolism while others have a slow metabolism. This misconception is more about the misidentification that body composition, especially fat mass, is the direct result of someone’s BMR. However, body composition is the result of highly complex interactions of several factors, of which BMR is but one (Clark 2012).
### Table 2. Equations for the estimation of basal metabolic rates (BMR) for adults or metabolic expenditure (VO₂) from activity. (ACSM 2006; Henry 2007; Kenny et al. 2017; Ramirez-Zea 2005)

<table>
<thead>
<tr>
<th>Equation Name</th>
<th>Mathematic Equation</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Cole</strong> (Normal weight)</td>
<td>Male: e⁻¹.₆₁₆⁻¹·₆₀₃₂₅₅⁺⁻₀.₄₇₂¹·₆⁰·₂₉₅₂⁺⁻₀.₀₉₄⁺⁻₀·₇₃₂·₆₀·₁₅₀⁺⁻₀·₂₀₃</td>
<td>BM = Body Mass (kg) H = Height (cm) A = Age (years, to closest year)</td>
</tr>
<tr>
<td></td>
<td>Female: e⁻¹.₃₉₁⁻¹·₆₀₃₂₅₅⁺⁻₀.₄₇₂¹·₆⁰·₂₉₅₂⁺⁻₀.₀₉₄⁺⁻₀·₇₃₂·₆₀·₁₅₀⁺⁻₀·₂₀₃</td>
<td></td>
</tr>
<tr>
<td><strong>Cole</strong> (Overweight/ Obese)</td>
<td>Male: e⁻¹.₃₆₀⁻¹·₆₀₃₂₅₅⁺⁻₀.₄₇₂¹·₆⁰·₂₉₅₂⁺⁻₀.₀₉₄⁺⁻₀·₇₃₂·₆₀·₁₅₀⁺⁻₀·₂₀₃</td>
<td>BM = Body Mass (kg) H = Height (cm) A = Age (years, to closest year)</td>
</tr>
<tr>
<td></td>
<td>Female: e⁻¹.₃₁₀⁻¹·₆₀₃₂₅₅⁺⁻₀.₄₇₂¹·₆⁰·₂₉₅₂⁺⁻₀.₀₉₄⁺⁻₀·₇₃₂·₆₀·₁₅₀⁺⁻₀·₂₀₃</td>
<td></td>
</tr>
<tr>
<td><strong>Harris-Benedict</strong> (imperial units)</td>
<td>Female: ((4.₃₆·BM + 4.₃·H - ₄.₇·A) + ₆₆₅)·ACF</td>
<td>BM = Body Mass (pounds) H = Height (inches) A = Age (years, to closest year)</td>
</tr>
<tr>
<td></td>
<td>Male: ((6.₂₃·BM + 1₂.₇·H - ₆.₈·A) + ₆₆₆)·ACF</td>
<td>ACF = Activity Conversion Factor (energy expenditure beyond resting level)</td>
</tr>
<tr>
<td><strong>Harris-Benedict</strong> (metric units)</td>
<td>Female: ((₉.₆·BM + ₁₈.₈·H - ₄.₇·A) + ₆₆₅)·ACF</td>
<td>BM = Body Mass (kg) H = Height (cm) A = Age (years, to closest year)</td>
</tr>
<tr>
<td></td>
<td>Male: (₁₃.₇·BM + ₅·H - ₆.₈·A) + ₆₆·ACF</td>
<td>ACF = Activity Conversion Factor (energy expenditure beyond resting metabolism)</td>
</tr>
<tr>
<td><strong>Henry/Oxford</strong></td>
<td>18-30 years: Females: ₀.₀₅₄₆·BM + ₂.₃₃ Males: ₀.₀₆₆₉·BM + ₂.₂₈ 30-60 years: Females: ₀.₀₄₀₇·BM + ₂.₉₀ Males: ₀.₀₅₉₂·BM + ₂.₄₈</td>
<td>BM = Body Mass (kg)</td>
</tr>
<tr>
<td><strong>Katch-McArdle</strong></td>
<td>9.₆·FFM + ₃₇₀</td>
<td>FFM = Fat-Free Body Mass (pounds)</td>
</tr>
<tr>
<td><strong>Mifflin-St Jeor</strong></td>
<td>Female: ₁₀·BM + ₆.₃₅·H - ₅·A - ₁₆₁ Male: ₁₀·BM + ₆.₃₅·H - ₅·A + ₅</td>
<td>BM = Body Mass (kg) H = Height (cm) A = Age (years, to closest year)</td>
</tr>
<tr>
<td><strong>Schofield</strong></td>
<td>18-30 years: Females: ₀.₀₆₂·BM + ₂.₀₃₆ Males: ₀.₀₆₃·BM + ₂.₈₉₆ 30-60 years: Females: ₀.₀₃₄·BM + ₃.₅₃₈ Males: ₀.₀₄₈·BM + ₃.₆₅₃</td>
<td>BM = Body Mass (kg)</td>
</tr>
</tbody>
</table>

### Expenditures for activities within lab (VO₂) in mL·kg⁻¹·min⁻¹

<table>
<thead>
<tr>
<th>Activity</th>
<th>VO₂ =</th>
<th>Factors</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Walking</strong></td>
<td>₀.₁·S + ₁.₈·(S·G) + ₃.₅</td>
<td>S = Speed (meters/min) G = Percent of Grade (expressed as a fraction)</td>
</tr>
<tr>
<td><strong>Running</strong></td>
<td>₀.₂·S + ₀.₉·(S·G) + ₃.₅</td>
<td>WR = Work Rate (kg·m·min⁻¹) BM = Body Mass (kg)</td>
</tr>
<tr>
<td><strong>Cycling</strong></td>
<td>₁.₈·(WR/BM) + ₃.₅ + ₃.₅</td>
<td>f = Step Frequency (steps/min) H = Step Height (meters)</td>
</tr>
<tr>
<td><strong>Arm-Cycling</strong></td>
<td>₃.₀·(WR/BM) + ₃.₅</td>
<td></td>
</tr>
<tr>
<td><strong>Stepping</strong></td>
<td>₀.₂·f + (₁.₃₃·₁.₈·H·f) + ₃.₅</td>
<td></td>
</tr>
</tbody>
</table>

*Note: Ramirez-Zea, et al indicate that for all persons Henry's and Cole's equations were more valid at prediction than Schofield's equation and Schofield's equation has been known to overestimate BMR in non-Caucasian persons. Henry’s equation is better at predicting BMR for males while Schofield’s equation may be better at predicting BMR for females.*
Additionally, there can be a limited understanding as to what Calories mean and how one’s dietary Caloric intake influences overall metabolism or relates to the Caloric expenditure from activity or normal physiological functions (Hall 2008, 2013, Thomas et al. 2013, Thomas et al. 2008). Contributing factors to metabolic rate are tissue growth and excessive repair of tissue damage. Either will increase metabolic rate (Clark 2015, Da Poian et al. 2010, Henry 2007, Phillips 2006, Tarnopolsky 2000, Thomas et al. 2008). Additionally, metabolic rates change in response to exertional stress (physical activity, exercise) as measured by a person’s level metabolic expenditure (VO2) during that physical activity (ACSM 2006).

Energetic Pathways and Adenosine Triphosphate (ATP)

Another important concept that sometimes gets lost is how energetic pathways necessary for regenerating ATP impact metabolic rates. In order to generate work, cells must have a turnover of ATP in order to keep concentrations high enough to meet demands by body cells and tissues. The rate of turnover will be impacted by the pathway selected while, at the same time, the selection of the pathway will dictate the rate of ATP turnover and overall availability (Figure 1). Within this concept of pathway selection, there is also the idea of efficiency of ATP regeneration that impacts the duration that a given pathway can be utilized before inefficiency leads to the need to use a different pathway or the pathway itself reaches a point of exhaustion.

Generally speaking, we break these into two distinct paths, but they are actually a continuum from low efficiency to high efficiency pathways. The continuum begins with the rapid return of ATP from a low efficient, highly exhaustible pathway (the phosphagen pathway) followed by less exhaustible pathways (glycolysis and lactate metabolism) and, eventually, the most efficient and a relatively inexhaustible pathway (Krebs cycle and the electron transport system). The continuum indicates how ATP turnover will take place based on the presence of intermediates within each of the pathways to allow for ATP turnover to meet demand and that is based on the combination of the intensity and duration of the activity (Figure 1). For example, when demand is high, the cells of the body will utilize a lower efficiency pathway (phosphagen and glycolysis) that allows for rapid return of ATP to meet the elevated demand. Yet, as demand reduces (or activity becomes too long for a lower efficiency pathway to be feasible) the cells will begin to utilize higher efficiency aerobic pathways, such as the Krebs cycle and the electron transport system.

![Figure 1. Timing for pathway used for ATP turnover during periods of activity.](image-url)
Moreover, the duration that any single pathway can be used in isolation is limited by several factors (Brancaccio et al. 2007, Da Poian et al. 2010, El-Bacha et al. 2010, Palmer et al. 2008, Smith et al. 2018, Vincent and Vincent 1997). The most readily recognized is the limitation of aerobic pathways based on the presence of oxygen at concentrations within the cell or via perfusion of the tissue to allow for continuous recycling of NAD and FADH within the mitochondria. This is encountered during activity levels beyond the aerobic threshold when there is a noted reduction in lipid metabolism and a concurrent increase in glycolytic and lactate metabolism (Peric et al. 2016, Purdom et al. 2018). Moreover, the glycolytic pathway is impacted first by the availability of glucose to the cell and then through inhibition of rate-limiting enzymes (i.e., phosphofructokinase, pyruvate dehydrogenase) that are negatively impacted by the elevation of pyruvate and lactate that occurs with excessive reliance on anaerobic ATP turnover (Da Poian et al. 2010, El-Bacha et al. 2010). Lastly, the regulation of the phosphagen system is limited by the concentration of precursors (creatine phosphate and ADP) but, more importantly, the creatine phosphokinase's inability to maintain its functional protein orientation following a few seconds of extensive use as the sole source for ATP being returned to the cells of the body (Brancaccio et al. 2007, Palmer et al. 2008, Vincent and Vincent 1997).

Additionally, the selection and use of any individual energetic pathways by cells will be impacted by a host of factors (Da Poian et al. 2010, Harvey et al. 2019, Jensen 2002, Lam and Ravussin 2016, Melzer 2011, Smith et al. 2018, Westerblad et al. 2010, Wołowczuk et al. 2008). First, there is the degree of metabolic flexibility of the individual that would allow the cell and tissue to use the specific metabolite (El-Bacha et al. 2010, Jeppesen and Kiens 2012, Smith et al. 2018). An issue of metabolism that is directly impacted by body composition is metabolic syndrome that develops from the excess adipose tissue-associated chronic inflammation that hinders flexibility (Booth et al. 2000, Clark 2012, Smith et al. 2018). Also important is ensuring the availability of the appropriate metabolites and enzyme activity within pathways that would allow for the reactions to proceed (El-Bacha et al. 2010, Kremmyda et al. 2011, Smith et al. 2018), allowing cells of the body to utilize carbohydrates (typically glucose metabolites), amino acids (via a process of deamination to form intermediates), and lipids (via β-oxidation to provide acetyl-CoA or ketone bodies (i.e., β-hydroxybutyrate, acetoacetate) to meet ATP demands. Further, certain tissues will be more apt to use certain metabolites and pathways than other tissues (Table 3) due to the presence or absence of specific enzymes (e.g., cardiac muscle and neurons favor aerobic metabolism) (Da Poian et al. 2010, El-Bacha et al. 2010, Kremmyda et al. 2011, Smith et al. 2018). Lastly, and almost the most important point in the selection process (Figure 1), is the demand for ATP at that moment in time (Purdom et al. 2018, van Loon et al. 2001, Westerblad et al. 2010).

Discussions about metabolic rates generally focus on the amount of energy expended to complete the task (obtained through the combustion or oxidation of fuels) and to maintain body mass. This has led to the idea of Caloric balance – the relationship between energy content in foods consumed compared with the energy expenditure from activities performed throughout the day, necessary for obtaining and maintaining a homeostatic body weight. Unfortunately, this thought is overly simplistic (Clark 2012, El-Bacha et al. 2010, Fern et al. 2015, Hall 2008, Thomas et al. 2013). The over-simplicity of thought most often stems from a lack of awareness for the requirement of having the appropriate metabolite available for a metabolic pathway to proceed coupled with an overt focus on energetic pathways (e.g., glycolysis, Krebs cycle, electron transport system) as the primary contributors to metabolism and metabolic rates (Curi et al. 2016). Additionally, there is a general lack of awareness of the impact that hormones have on overall metabolic rates that may occur independent of the Caloric balance along with a lack of understanding as to the true deficit or surplus of Calories necessary for instigating body compositional changes (Clark 2012, Fern et al. 2015, Foster-Schubert and Cummings 2006, Hall 2008, 2013, Thomas et al. 2013). We must remember that the availability of the required nutrients within metabolism are as least as important as the Caloric balance of the diet (Da Poian et al. 2010, El-Bacha et al. 2010, Fern et al. 2015, Thomas et al. 2013). This means that, when evaluating or discussing metabolism, we must do so based on nutrition and a nutrient balance, the relationship between nutrient utilization based on tissue specific demands, and dietary consumption of those nutrients (Figure 2) and not simply Caloric balance.

Nutrition

Nutrition, diet, and nutrient balance

The diet of an individual is meant to meet the nutrient demands of metabolism based on the combination of BMR and the overall demands for maintaining, or regaining, homeostasis. Five characteristics of a diet (adequacy of nutrients, balance of dietary components, Caloric contents, moderation of amounts, and variety) must be integrated to ensure proper nutrient balance (Figure 2).

Figure 2. The nutrient (fuel) balance versus Caloric balance conceptualized.

continued on next page
In terms of nutrient balance, diets consist of six generalized categories of nutrients: water, carbohydrate, protein, lipid (fat), nucleic acids, and vitamins and minerals. Each category of nutrient serves both a unique independent role for homeostasis of the body while also functioning in combination with others within the totality of cellular metabolism. Nutrient use in metabolism will vary based on the tissues, responses to stresses being placed on the tissues or hormonal regulation, and the nutrient availability to the individual (Antonio et al. 2015, Curi et al. 2016, Da Poian et al. 2010, El-Bacha et al. 2010, Fern et al. 2015, Goncalves-Alfenas et al. 2010, Hellerstein 1999, Uauy et al. 1999).

<table>
<thead>
<tr>
<th>Tissue</th>
<th>Nutrient used &amp; nutrient preference (if applicable)</th>
<th>Storage</th>
<th>Nutrient release for use at other</th>
</tr>
</thead>
<tbody>
<tr>
<td>Adipose</td>
<td>CHO Glu FFA</td>
<td>FFA (via lipogenesis)</td>
<td>FFA (via lipolysis)</td>
</tr>
<tr>
<td>Blood Cells</td>
<td>Glu Pyr LA</td>
<td>None</td>
<td></td>
</tr>
<tr>
<td>Bone Tissue/Skeleton</td>
<td>Glu CHO</td>
<td>aa (via Protein)</td>
<td>aa (via proteolysis)</td>
</tr>
<tr>
<td>Cardiac Muscle</td>
<td>Glu FFA LA and Pyr KB FFA&gt;KB&gt;Glut</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Kidney</td>
<td>Glu FFA</td>
<td></td>
<td>Glu (via gluconeogenesis)</td>
</tr>
<tr>
<td>Neuron</td>
<td>Glu KB</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Liver</td>
<td>Glu LA and Pyr (for gluconeogenesis) aa FFA</td>
<td>FFA (via lipogenesis) Glu (via Glycogen)</td>
<td>Glu (via glycogenolysis gluconeogenesis) FFA (via lipolysis) KB (via transamination, ketogenesis)</td>
</tr>
<tr>
<td>Skeletal Muscle</td>
<td>CHO Glu FFA LA and Pyr KB Glu ≥ FFA ≥ KB*</td>
<td>Glu (via Glycogen) aa (via protein synthesis)</td>
<td>Pyr (via glycolysis) aa (via proteolysis) LA (via pyruvate reduction)</td>
</tr>
</tbody>
</table>

*Dependent upon intensity of activity, oxygen and metabolite availability

**Table 3.** Summary of nutrient utilization based on tissues and cell classifications (CHO=carbohydrates, Glu=glucose, KB=Ketone Body, Pyr=Pyruvate, LA=Lactate, FFA=Fatty-Acid, aa=amino acid).
One aspect of integration between nutrition and metabolism is seen in the regeneration of ATP. There are four distinct fuel sources that provide varying amounts of energy: carbohydrates (approximately 4 Cal/g), proteins/amino acids (approximately 4 Cal/g), ketones (approximately 7 Cal/g), and lipids (approximately 9 Cal/g, for longer chain fatty acids, and 7 Cal/g, for shorter chain fatty acids).(Da Poian et al. 2010, Fern et al. 2015). It’s important to realize that these values may not accurately describe the return of ATP for use in energetic pathways. For example, the Caloric values returned from lipids show the greatest variance between molecules, based on the size of the fatty-acid molecule and level of saturation, and proteins actually contain more stored energy per gram consumed than is indicated as available for energetic transfer at the cellular levels. More importantly, hormonal and regulatory signals (Table 4) will dictate the pathway of activation and the end result of metabolism of these molecules within cells (Curi et al 2016, Da Poian et al 2010, El-Bacha et al 2010, Goncalves-Alfenas et al 2010, Hellerstein 1999, Jeppesen and Kiens 2012, Kim et al. 2016).

Additionally, nutrients used for energetic pathways are also the same nutrients that serve as building blocks for the larger macromolecules that comprise the bulk of the mass of the body (Carbone and Pasiakos 2019, Kerksick et al. 2018, Lambert et al. 2004, Phillips et al. 2015, Smith et al. 2018, Tarnopolsky 2000). This combination of use of nutrients within the various metabolic pathways allows us to derive nutrient balance. For example liver, skeletal muscle and adipose cells will synthesize larger macromolecules (structural and contractile proteins, glycogen, fatty-acids and lipid droplets) for maintaining or regaining homeostasis within the tissues when intake is greater than utilization for energy balance, or to act as stores of nutrients for times when nutrient use outpaces intake (Carbone and Pasiakos 2019, Da Poian et al. 2010, Fern et al. 2015, Jensen 2002, Phillips 2006, Smith et al. 2018). It is important to note that the misconception is that storage will take place strictly as lipids in adipose tissue based on the Caloric imbalance. In reality, storage is based on need for the nutrient that regulates growth and storage taking place as carbohydrates, proteins and lipids and these are all in response to homeostatic stresses, hormonal signals (Table 4) and the availability of nutrients in excess.
### Metabolism and Nutrition: Integration of Concepts in a Holistic Approach to Teaching Metabolism

<table>
<thead>
<tr>
<th>Hormone</th>
<th>Impact on metabolism</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testosterone/Adrenal Androgen</td>
<td>↓ Lipogenesis and ↑ Lipolysis, ↑ Protein Synthesis</td>
</tr>
<tr>
<td>Estrogen</td>
<td>↓ ROS, ↑ Aerobic Metabolism Modification of Lipid Metabolism (tissue-based Lipogenesis)</td>
</tr>
<tr>
<td>Growth Hormone (Small MW)</td>
<td>↑ Lipolysis and ↓ Lipogenesis ↓Glucose Utilization</td>
</tr>
<tr>
<td>Growth Hormone (22 kD and Larger MW)</td>
<td>↓ Lipogenesis and ↑ Lipolysis, ↑ Protein Synthesis</td>
</tr>
<tr>
<td>Insulin</td>
<td>↑ GLUT 4 Mediated Glucose Uptake ↑ Lipogenesis and ↓ Lipolysis ↑ Glycogenesis and ↓ Glycogenolysis ↑ Protein Synthesis</td>
</tr>
<tr>
<td>Glucagon</td>
<td>↓ GLUT 4 Mediated Glucose Uptake ↑ Lipolysis and ↓ Lipogenesis, ↓ Glucose Utilization ↑ Glycogenolysis and ↓ Glycogenesis, ↑ Gluconeogenesis (at hepatocytes)</td>
</tr>
<tr>
<td>Insulin-like Growth Factor (IGF)</td>
<td>↓ Lipogenesis and ↑ Lipolysis, ↑ Protein Synthesis</td>
</tr>
<tr>
<td>Cortisol</td>
<td>↓ Glucose Utilization ↓ GLUT 4 Mediated Glucose Uptake ↑ Lipolysis and ↓ Lipogenesis* ↑ Glycogenolysis and ↓ Glycogenesis ↑ Gluconeogenesis (hepatocytes) ↑ Proteolysis, Transamination and Deamination</td>
</tr>
<tr>
<td>Triiodothyronine (T₃) and Thyroxine (T₄)</td>
<td>↑ Lipolysis and ↓ Lipogenesis ↑ Mitochondrial Biogenesis Upregulation of Uncoupling Proteins (↑ Thermogenesis) ↑ Protein Synthesis</td>
</tr>
<tr>
<td>Catecholamines (Epinephrine and Norepinephrine)</td>
<td>↑ GLUT-1, GLUT-10 glucose uptake ↑ Lipolysis and ↓ Lipogenesis, ↓ Glucose Utilization ↑ Glycogenolysis and ↓ Glycogenesis, ↑ Gluconeogenesis (hepatocytes)</td>
</tr>
<tr>
<td>Muscle Ischemic Factor (MIF)</td>
<td>↑ Mitochondrial Biogenesis within Skeletal Muscle ↑ Energetic Enzymes (Glycolytic and Mitochondrial)</td>
</tr>
<tr>
<td>AMP-kinase (AMPk)</td>
<td>↑ GLUT-1 Glucose Uptake at Skeletal Muscle ↑ Mitochondrial Biogenesis and Mitochondrial Enzymes</td>
</tr>
<tr>
<td>Leptin</td>
<td>Δ Insulin Sensitivity, ↑ Lipogenesis and ↓ Lipolysis Antagonist to Ghrelin Regulation of Hypothalamic Functions for Energetics and Feeding</td>
</tr>
<tr>
<td>Ghrelin</td>
<td>↑ Growth Hormone Production and Release Antagonist to Leptin regulation of Hypothalamic Functions for Energetics and Feeding</td>
</tr>
<tr>
<td>Tumor Necrosis Factor-α (TNF-α)</td>
<td>↓ GLUT 4 Mediated Glucose Uptake ↓ Glucose Utilization at non-Glucose-Obligated Tissues</td>
</tr>
<tr>
<td>Interleukin-6 (IL-6)</td>
<td>↑ GLUT-1, GLUT-4, GLUT-10 Mediated Glucose Uptake ↑ Insulin Sensitivity ↑ Lipolysis via PPAR Modification</td>
</tr>
<tr>
<td>Interleukin-1b (IL-1b)</td>
<td>↓ GLUT 4 Mediated Glucose Uptake ↓ Glucose Utilization at non-Glucose-Obligated Tissues</td>
</tr>
<tr>
<td>Endocannabinoids</td>
<td>Regulation of Leptin and Ghrelin Receptors in Hypothalamus altering Feeding Responses Regulation of Aerobic Metabolism at Skeletal Muscle</td>
</tr>
</tbody>
</table>

*At excessive levels, or when insensitive to cortisol, lipolysis may be reduced, and lipogenesis may be more pronounced.

*Table 4. Hormone and metabolite generalized impact on tissue metabolism and nutrient utilization.*
Metabolism and Nutrition: Integration of Concepts in a Holistic Approach to Teaching Metabolism

Nutrient Requirements

The requirements for nutrients for any individual will be based on the same host of factors that helped to estimate BMR. Along with the factors regulating nutrient requirements, there are physiological and psychological regulators of feeding that not only alter a want for food but will also direct changes in BMR that have been traditionally linked with thyroid hormones (Figures 3 and 4) (Clark 2012, Da Poian et al. 2010, El-Bacha et al. 2010, Fern et al. 2015, Hall 2008). However, the means by which these factors impact nutrient requirements deviates from their impact on BMR because they focus on ensuring a nutrient load necessary to allow for proper hormonal regulation of growth and maintenance of tissues.

A concept that is important to discuss with students entering health careers is the changing need for lipids and amino acids across the age range of patients that they will encounter (Kerksick et al. 2017, 2018, Uauy et al. 1999). Additionally, there is a varying degree of understanding as to the necessity for macronutrients, especially protein, by those who exercise or are attempting to shift body composition for health benefits (Antonio et al. 2015, Carbone and Pasiakos 2019, Clark 2015, 2019 Lambert et al. 2004, Phillips 2006, Phillips et al. 2015, Tarnopolsky 2004). There is also a higher carbohydrate load, due to tissue growth and increased neuron function, that is seen in children, juveniles, and adolescents that may explain the increased need and desire for carbohydrates within their diet (Giovannini et al. 2000, Stephen et al. 2012). This requirement does not currently agree with our societal aversion to carbohydrate consumption by young people based on a prominent bias that increased consumption of carbohydrates will lead to metabolic and behavioral issues. Moreover, without addressing the nutrient load issue, there might be a loss of awareness that the student who is actively learning will also need this increased carbohydrate load to support increases in cognitive function (Sieber and Traystman 1992).

**Figure 3.** Metabolism and feeding regulation based on hormone and metabolite interactions during low nutrient load.
Carbohydrate Balance

Many discussions about carbohydrate balance focus on the importance of hormonal regulation by insulin and glucagon. While these hormones play important roles in glucose homeostasis, much of the body’s carbohydrate metabolism will actually function independently of either hormone (Table 4). The rationale for this statement is that a level of glucose uptake by tissues can and does take place via non-GLUT-4 transporters, and so is independent of insulin (Curi et al. 2016, Ebeling et al. 1998, El-Bacha et al. 2010, Evans et al. 2019, Hilder et al. 2005). Additionally, focusing on only the roles of insulin and glucagon in carbohydrate balance ignores the contribution of other carbohydrates (i.e., pentose pathways) in overall carbohydrate metabolism at rest and during activity (Del-Corso et al. 2019, Fuchs et al. 2019, Mahoney et al. 2018, Melzer 2011).

Furthermore, the need to move glucose into cells via increased activity of insulin-regulated GLUT-4 transporters occurs only in select tissues (adipose, skeletal muscle) and only when plasma glucose concentrations are in excess of the capacity of the other glucose transporters, such as GLUT-1 (Curi et al. 2016, Da Poian et al. 2010, El-Bacha et al. 2010, Evans et al. 2019). And this does not necessarily alter carbohydrate metabolism, as typically discussed, even though it is recognized that insulin and glucagon may antagonistically impact enzymes in the glycolysis, glycogenolysis and glycogenesis pathways. It is known that increased insulin levels direct metabolic actions toward glycogenesis, while limiting glycolysis or glycogenolysis, through regulation of the phosphatase and hexokinase enzymes, and trigger lipogenesis in adipose tissue (El-Bacha et al. 2010, Hellerstein 1999). It is also accepted that increased glucagon levels promote glycogenolysis while limiting glycolysis and glycogenesis by regulating these same enzymes in the direct opposite direction as insulin.

Figure 4. Metabolism and feeding regulation based on hormone and metabolite interactions during high nutrient load.
Ignoring the regulatory role of hormones such as insulin on the membrane concentration of GLUT transporters or enzyme regulation, there are several aspects of carbohydrate metabolism that must be discussed as they relate to the idea of a carbohydrate balance. Among these is the role that glucose takes in the regulation of metabolic processes and energetics for the cells of the body.

First, we must note how various tissues might differentially utilize glucose in their metabolic processes, from glucose-dependent/glucose-obligated tissues (neural tissues, blood cells) that use insulin-independent GLUT-1 transporters to take in glucose, to tissues (adipose tissue, liver, skeletal muscle) that prefer glucose, but are not dependent on it, and are impacted by the actions of both insulin and glucagon, versus those with a preference for things not glucose (cardiac muscle). Based on this level of tissue dependency, a carbohydrate balance can be established in which it is recommended that a person consume 120 g of glucose per day to meet the demands of just the neural tissues (Sieber and Traystman 1992).

Moreover, the rate of glucose use in skeletal muscle will vary based on the intensity and duration of activity and this can drastically alter overall glucose balance (Evans et al. 2019, Hilder et al. 2005, Melzer 2011). Similarly, engaging in high cognitive activities will also drastically alter carbohydrate balance due to increased neuronal functions beyond the basal 120 g per day (Sieber and Traystman 1992, Smith et al. 2018). Additionally, healthy active individuals should consume a range of 8-12 g carbohydrates per kg of body mass to ensure proper glycogen stores in skeletal muscle and liver (Murray and Rosenbloom 2018). These values do not address the necessity for dietary fiber consumption (approximately 30 g per day) that can impact carbohydrate balance when consuming carbohydrates from whole food sources and not processed sources. Fiber is included in the listing of carbohydrates on nutritional labels but cannot be included in the carbohydrate balance for the individual due to the inability to digest and absorb these forms of carbohydrate (Fern et al. 2015).

Second is the need to ensure that cells dependent on glucose have a stable blood concentration of glucose (80-90 mg/dL) to meet metabolic demands that must occur without the individual having to consistently consume glucose. To do this, hepatocytes and renal cells will perform gluconeogenesis (Rui 2014). Textbooks incorrectly define this pathway, as the production of glucose from noncarbohydrate sources. Unfortunately, this does not match the metabolic pathway where a cascade of biochemical reactions involving glucose metabolites (i.e., pyruvate, lactate) leads to the production of glucose, thereby providing new glucose for the cells of the body. In performing gluconeogenesis, hepatocytes (and to a lesser extent renal cells) will metabolize glucose metabolites (i.e., pyruvate, lactate), without regard to the source (carbohydrate, lipid or amino acid) into glucose that will be released into circulation for use at glucose-obligated tissues or tissues experiencing a higher demand for ATP. By clearing pyruvate and lactate for use in gluconeogenesis, the liver establishes a cycle of exchange with peripheral tissues (the Cori cycle) that allows the liver to meet homeostatic demands for glucose, independent of glucose consumption (Rui 2014).

The rate of converting glucose metabolites into glucose is dependent on the dietary consumption of carbohydrates relative to peripheral utilization and is known to increase during periods of increased skeletal muscle activity to ensure that the elevated demands are met. Additionally, when levels of glucose metabolites are excessively low, or during periods of inflammation, hormonal regulation of hepatocytes will generate pyruvate or lactate from amino acids such as alanine, glutamine through a deamination process that provides more pyruvate to be metabolized into glucose (Rui 2014). This deamination process may be where the confusion of the source for metabolites in gluconeogenesis stems, but deamination and transamination are not gluconeogenesis nor is gluconeogenesis deamination or transamination. Moreover, when glucose levels are below optimal, hormonal regulation will lead to available glycogen stored in liver or skeletal muscle to be catabolized to free glucose for release into circulation (liver) or for use within the skeletal muscle itself (Murray and Rosenbloom 2018).

The third aspect of carbohydrate metabolism directly opposes utilization and instead focuses on storage of carbohydrates under regulation by insulin (Table 4). Carbohydrates are traditionally thought of as being stored as glycogen (Murray and Rosenbloom 2018). When glucose consumption from a meal exceeds 1-1.2 g/kg body weight/hour, hormonal changes induce the liver and skeletal muscle to store that glucose as glycogen. However, a higher level of consumption does not lead to greater storage, as only a finite amount (approximately 600 g) of glycogen can be stored with 5 out of every 6 grams stored in the liver and the remainder stored intramuscularly. Given this limited storage capacity, there needs to be other options. Under correct hormonal signals, high levels of intracellular glucose, or accumulation of Krebs cycle intermediates such as malate or malonyl-CoA, hepatocytes and adipocytes will begin the process of lipogenesis, thereby storing the carbohydrates within fatty-acids or as glycerol molecules necessary for triglyceride or phospholipid production (Hellerstein 1999, Jensen 2002). Along with storage in lipid, carbohydrates can undergo metabolic reactions to form the backbone and side chains for various non-essential amino acids that the body produces.

Lipid Balance

Just as with other aspects of metabolism, lipid metabolism is also associated with several student misconceptions. These include misconceptions about the amount of lipid one should consume, that use of lipids for energetic purposes would only occur under distinct levels of physical activity, and that lipids are simply extra Calories stored in a metabolically inert tissue.
The latter two misconceptions stem from a poor application of the fat\textsubscript{max} and fat\textsubscript{true} intensities of exercise presented in the exercise science literature with an additional concern being the mistaken belief that dietary supplements cause greater fat loss (Booth et al. 2000, Carey 2009, Clark 2012, 2019, Croci et al. 2014, Inchiosa 2011). Yet, there are many aspects of lipid metabolism that have nothing to do with these notions. Unlike for carbohydrates, where we can convert carbohydrates into forms that can be used to ensure homeostasis, there are distinct forms of lipids (essential fatty acids) that must be consumed to allow for homeostasis (Uauy et al. 1999). These essential fatty acids (EFA), classified as the n-3 and n-6 fatty-acids or more commonly referenced as omega-3 and omega-6 fatty-acids, allow for the formation of longer chain monounsaturated (MUFA) and polyunsaturated (PUFA) fatty-acids necessary for the formation of membranes for cells of the body (Uauy et al. 1999). It is recommended that adults consume 2-3 g of the n-3 PUFA (eicosapentaenoic acid (EPA), docosahexaenoic acid (DHA) and alpha-linoleic acid (ALA)) per day (2 g of ALA and about 0.5 g of EPA and DHA), along with 12-17 g of n-6 fatty acids per day (Kremmyda et al. 2011, Uauy et al. 1999).

Moreover, lipid consumption has a direct impact on the ability of cells to generate a host of hormones (steroid hormones and prostaglandins), as well as regulate cellular metabolic processes, inflammatory responses to systemic inflammation signals, and cell cycling (Kremmyda et al. 2011). In reference to metabolic processes, the greatest impact comes through adipose tissue production and release of adipokines (i.e., leptin) that regulate some basal metabolic processes at the level of the hypothalamus; this regulation has been classically attributed to thyroid hormones (Table 4 and Figures 3 and 4) (Clark 2012, Dyck 2009, Foster-Schubert and Cummings 2006, Jéquier 2002). Additionally, there is an advantage to the use of lipids as a fuel source for ATP turnover, given the 3-4 fold increase in ATP return obtained from lipids relative to an equal quantity of carbohydrates (El-Bacha et al. 2010). Moreover, unlike with carbohydrates where storage is limited to <1 kg, there appears to be no limit to the body’s capacity to store lipids.

It is important to recognize that lipogenesis will take place in all cells of the body. However, the greatest amount of lipid production related to whole-body metabolism will occur in hepatocytes and adipocytes under distinct metabolite availability and hormonal regulation (Hellerstein 1999, Jensen 2002, Kremmyda et al. 2011, Uauy et al. 1999). While lipogenesis is popularly thought to take place with excessive Caloric consumption, the instigator for lipogenesis of non-essential fatty acids (i.e., palmitic acid, oleic acid, linoleic acid, stearic acid) appears to be intracellular levels of glucose, fructose, or malonyl-CoA, and not excessive Caloric consumption (Carta et al. 2017, Hellerstein 1999). This means that any carbohydrate in excess (especially fructose) intake may induce lipogenesis regardless of Caloric balance, primarily due to regulatory actions of insulin at the level of adipose tissue (Hellerstein 1999, Jensen 2002). This is a phenomenon that is an issue for those who indicate as being overfat (Clark 2012) or metabolically obese, even though they appear to be thin, or have a normal body composition, or report consuming food that would place their Caloric balance as being less than their indicated BMR (Bacon and Aphramor 2011, Ruderman et al. 1981).

Moreover, this increased rate of lipogenesis associated with excessive carbohydrates in circulation triggers adipose tissue-embedded macrophages to initiate inflammatory responses that lead to diseases associated with overfatness (Booth et al. 2000, Clark 2012, Foster-Schubert and Cummings 2006, Smith et al. 2018). Of the various factors that initiate lipogenesis, high levels of fructose uptake by adipose cells may be the most powerful stimulus (Hellerstein 1999, Jensen 2002).

Additionally, lipogenesis for EFA-derived lipids is not linked to dietary Caloric content or carbohydrate concentrations but is dependent on delivery of dietary lipids to cells following hepatic metabolism as well as requirements for lipids by the respective cells (Kremmyda et al. 2011, Uauy et al. 1999). Along with increased lipogenesis stemming from elevated carbohydrate levels, there is the lipogenesis of lipoproteins (VLDL, LDL, HDL) associated with dietary lipid ingestion secondary to enzymatic regulation of hepatocyte activity. The production of lipoproteins is important as some of them function to transports lipids to body cells for use in metabolic processes such as hormone synthesis and membrane assembly (Jensen 2002, Kremmyda et al. 2011).

With regard to energy metabolism, lipid use is predominantly a hormonally regulated process (Table 4) via hormone-sensitive lipase and carnitine transport to mitochondria (Clark 2019, Jeppesen and Kiens 2012). Additionally, consumption of sympathomimetic substances such as caffeine, monoamines, and ephedra alkaloids will activate the pathway via the adrenergic receptor, allowing for additional lipid mobilization and possible utilization (Clark 2019, Jeukendrup and Randell 2011, Stohs and Badmaev 2016). Additionally, when ATP demand is reduced, metabolically flexible tissues will increase lipid utilization and preferentially select lipids as their predominate fuel source (Carta et al. 2017, Da Poian et al. 2010, El-Bacha et al. 2010, Melzer et al. 2018, Smith et al. 2018). It has been approximated that, at rest, three-quarters of all ATP is generated by the utilization of β-oxidation to form acetyl-CoA for use in the aerobic pathways (Carta et al. 2017; Da Poianet al. 2010; El-Bacha et al. 2010; Kremmyda et al. 2011; Purdom et al. 2018). Furthermore, some aerobic-obligated tissues (i.e., cardiac muscle) function as lipid preferential tissues due to restricted levels of glycogen stores while other tissues (i.e., neural tissues) regularly use metabolites (ketone bodies) that originate from lipid metabolism for energetic purposes (El-Bacha et al. 2010; Smith et al. 2018).

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Moreover, it is recognized that lipids allow for greater total ATP turnover at a higher efficiency than carbohydrates and provide greater potential for completing work, providing a rationale for increased lipid composition in the diets for those who engage in prolonged exercise or endurance athletic events (Croci et al. 2014, Jensen 2002, Harvey et al. 2019, Jeppesen and Kiens 2012, Melzer 2011, Paoli et al. 2015, Peric et al. 2016, Westerblad et al. 2010). Yet, while more efficient, the rate of return is much lower than what is obtained from carbohydrates and this may contribute to the inconsistent reports of benefits in performance for those utilizing higher fat diets during endurance events (Burke 2015, Burke et al. 2017, Harvey et al. 2019, Pinckaers et al. 2017).

Given the use of lipids during periods of low carbohydrate concentrations or when ATP demands allow for the preferential use of lipids, one can generate the right conditions to accentuate fat utilization (Carey 2009, Clark 2012, Carta et al. 2017, Croci et al. 2014, Kremmyda et al. 2011, Peric et al. 2016). This is a common treatment to induce loss of fat mass in those who are overfat and leads to a very interesting question: Where does fat go during weight loss? To formulate the answer to this question, it is very important to remember the stoichiometry that explains lipid utilization in which the reaction of one of the more readily utilized fatty acid, palmitic acid, can be summarized as (Carta et al. 2017; Kremmyda et al. 2011; Peric et al. 2016):

\[
\text{1 palmitic acid (C}_{16}\text{H}_{32}\text{O}_2) + 23 \text{O}_2 \rightarrow 16 \text{CO}_2 + 16 \text{H}_2\text{O}
\]

This means that when fat mass is lost, it is lost by becoming carbon dioxide and water, molecules that will be eliminated by normal excretory functions (respiration, urination, sweating).

Prolonged use of lipids for ATP regeneration leads to the production of ketone bodies such as β-hydroxybutyrate and acetoacetate (Manninen 2004, Nylen et al. 2009, Rui 2014). What is interesting is that, while ketocidosis is popularly indicated as being an adverse state, when subsequently combined with normal glucose concentrations ketones can provide a benefit to individuals with a history of excessive oxidative stress. This is due to the fact that β-hydroxybutyrate can very easily be converted back to acetyl-CoA within aerobic tissues without the redox reactions required to form acetyl-CoA from other fuel sources (Hashim and VanItallie 2014, Keins and Astrup 2015, Manninen 2004, Nylen et al. 2009, Paoli et al. 2013, Volek and Westman 2002). Thus, diets, such as restricted carbohydrate diets that induce the formation of ketones, have become a popular intervention for individuals with metabolic syndrome, cardiovascular disease or neurodegenerative diseases (Clark 2012, Garretson et al. 2016, Hashim and VanItallie 2014). However, the physiological and psychological issues associated with the onset and maintenance of such diets due to the dietary restrictiveness and known social pressures associated with continuous use, does result in low rates of attrition (Bostock et al. 2020; Keins and Astrup 2015).

**Protein (Amino Acid) Balance**

Discussion of protein (amino acid) balance and dietary requirements can be difficult to cover in the curriculum, as the topic has been misappropriated by fitness bloggers and gym enthusiasts (Clark 2019, Duellman et al. 2008). Discussions of protein balance and metabolism are often linked to the gain or maintenance of fat-free mass (skeletal muscle, bone) more than energetics (Antonio et al. 2015, Carbone and Pasiakos 2019, Clark 2015, 2019, Lambert et al. 2004, Phillips 2006, Tarnopolsky 2004). While important in the synthesis of fat-free mass, some amino acids and their metabolites have been shown to also act as key non-hormonal regulators of overall metabolism not directly related to overall fat-free mass and they also serve as precursors in the synthesis of neurotransmitters (i.e., serotonin, dopamine) and hormones (i.e., epinephrine, melatonin) (Ciuris et al. 2019, Fernstrom and Fernstrom 2007, Goncalves-Alfenas et al. 2010, Kamei et al. 2020, Kreider et al. 2017).

When discussing protein balance, just as with lipids, it is important is remember that certain amino acids must be consumed (essential amino acids, EAA). The consumption of EAA is highly important, as the cells of the body are either unable to synthesize them at all or to synthesize them at a high enough quantity to meet demands for the EAA within protein metabolism. This need for consumption of EAA has led to a belief that supplementation of select EAA, along with a general overall increase in protein consumption, may be necessary for individuals who are highly active and wish to induce hypertrophication of fat-free mass (Antonio et al. 2015, Carbone and Pasiakos 2019, Clark 2019, Duellman et al. 2008, Lambert et al. 2004, Phillips 2006, Phillips et al. 2015). Yet, this relationship may not be correct as the overall level of response is more linked with training stimulus than total protein consumed (Clark 2019, Rossato et al. 2017).

This author (Clark 2019) previously indicated an optimal level of effectiveness at the higher end of the recommended level (1.8 g protein/kg body mass/day) with no indication for additional beneficial effect independent of training beyond this level. Others have suggested an optimal range of 1.1-1.3 g protein/kg body mass/day for an exerciser involved in resistance or endurance training (Phillips 2006, Tarnopolsky 2004). Even so, there is general acknowledgment that the recommendation for protein consumption will vary based on age and level of activity for the individual, with a total protein consumption range of 0.8-2.2 g protein/kg body mass per day being given for most adults (Carbone and Pasiakos 2019, Clark 2019, Goncalves-Alfenas et al. 2010, Phillips 2006, Phillips et al. 2015, Rothman 2010, Tarnopolsky 2004, Tarnopolsky 2000, Young and Pellet 1994). Additionally, these values will change when protein balance is examined based on gender, or for those who are attempting to diet to reduce body mass while maintaining fat-free mass (Carbone and Pasiakos 2019, Clark...
need to increase their protein intake to offset the negative state established by the various stressors that they are encountering.

Protein metabolism is a contentious topic related to energetics. There are two distinct areas where amino acid and protein balance become involved with energetics. Amino acids can act as a regulator (i.e., creatine), a precursor to carbohydrates for entry into gluconeogenesis (i.e., alanine, glutamine), or as a precursor for metabolites in the Krebs cycle (e.g. branch-chained amino acids).

The first is the direct involvement of the amino acid, creatine, in the anaerobic energetic pathway of ATP turnover, the phosphagen system. Creatine and creatine kinase allow cells to cycle ATP at a rate high enough to last for the first few seconds of whole-body activity independent of any fuel source (Figure 1). To meet this demand, it is indicated that consumption of 3 g creatine per day will meet most individuals' needs and this can be largely met through normal intake of animal dietary protein sources (Kreider et al. 2017). There has been the suggestion that additional creatine intake (greater than 6 g creatine per day) will allow for an extension of the phosphagen system and thus provide additional performance benefit (Kreider et al. 2017). However, this metabolic pathway is not limited by the amount of creatine but by the amount of the regulatory enzyme, creatine kinase (Clark 2019). When benefit has been reported, it typically is associated with training intensities that are beyond maximal efforts that stimulate a tissue specific adaptation (i.e., hypertrophication) which in turn increases phosphagen system enzymes, including creating kinase (Cooke et al 2014; Kreider et al 2017; Lanhers et al. 2017). Interestingly, it has been shown that for specific conditions (head trauma, concussion) creatine supplementation appears to have a positive impact on recovery and repair (Dean et al. 2017; Oliver et al. 2018). To date, no rationale has been provided for this benefit; it has been speculated that it may arise through maintaining mitochondrial functions following trauma to the neurons or by allowing reconstitution of membrane dynamics.

The other avenue of involvement is use as a fuel source by providing molecules that can be metabolized into carbohydrates for use in ATP turnover. Most amino acid utilization by skeletal muscle will be regulated hormonally during periods of carbohydrate restriction and is indicated as providing fuel sources for ATP turnover during exercise (Phillips 2006; Tarnopolsky 2004). Skeletal muscle can use select amino acids to produce pyruvate, acetyl-CoA, or intermediates of the Krebs cycle (i.e., α-ketoglutarate, succinyl-CoA, fumarate, oxaloacetate), allowing continuation of ATP turnover during periods of low carbohydrate balance (Da Poian et al. 2010, El-Bacha et al. 2010, Smithet al. 2018). The issue here is that most equations of nutrient utilization (e.g., respiratory exchange ratio, respiratory quotient) indicate that protein has minimal contribution to whole-body energetics, even if proteolysis is elevated during prolonged activity or

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in cases of nutrient restriction (Carbone and Pasiakos 2019, Goncalves-Alfenas et al. 2010, Tarnopolsky 2004). Additionally select amino acids will undergo hepatic transamination with a secondary ketone, forming ketone bodies (β-hydroxybutyrate, acetoacetate) that will be released into the circulation to provide fuel sources necessary to meet ATP demands. (Rui 2014). While both processes occur throughout the day, they each increase both in utilization and rate of reaction during periods of prolonged fasting, low carbohydrate balance, or during inflammation when hormonal signals instigate an increase in proteolysis (Da Poianet al. 2010, El-Bacha et al. 2010, Fern et al. 2015, Goncalves-Alfenas et al. 2010, Rui 2014). A problem related to protein metabolism that can occur is that, without proper hormonal stimulation, excessive consumption will not lead to storage such as is seen with other nutrients (Clark 2019, Da Poian et al. 2010, El-Bacha et al. 2010, KerkscK 2017, Phillips 2016). Amino acids present in excess need to be deaminated or transaminated within the liver producing carbohydrate and ketone bodies that can be used in other metabolic processes (Rui 2014). Excessive consumption of proteins and amino acids for energetic purposes can lead to the accumulation of ammonia and ammonium within the plasma and increased urea production by the liver (Goncalves-Alfenas et al. 2010, Rui 2014). This can result in increased renal stress for individuals who have hepatic or renal issues, leading to not recommending increased protein ingestion for these individuals. Yet, high levels of protein ingestion have not been seen to instigate issues for healthy and active individuals. Along with the worry about renal stress is the opinion that increased animal protein consumption is associated with other long-term diseases, such as cardiovascular disease, and this has led to a position for utilizing plants as a primary source of dietary protein (Ciuris et al. 2019, Leroy and Cofnas 2020, van Vliet et al. 2015, Venderley and Campbell 2006, Young and Pellet 1994). There is some evidence to support the use of plant-based protein sources when dealing with issues of cardiovascular health and lipoprotein metabolism (AHANC et al. 2006, Leroy and Cofnas 2020, Levine et al. 2014). Moreover, there is evidence to support the use of plant-based sources to meet protein, amino acid and nitrogen needs for healthy individuals (Leroy and Cofnas 2020; van Vliet et al. 2015; Venderley and Campbell 2006; Young and Pellet 1994). Yet, there is a concern for ensuring consumption of not only the entirety of essential amino acids and the minimum requirement of creatine, but also the additional vitamins and minerals obtained from animal protein sources that may limit benefits of using plants as the sole protein source without requiring dietary supplements (Carbone and Pasiakos 2019, Ciuris et al. 2019, Clark 2019, Dodd et al. 2020, Freeland-Graves et al. 2013, Phillips et al. 2015, Tarnopolsky 2004). Additionally, there are indications that certain sources of plant protein (i.e., soy) may impact metabolic and hormonal functions by acting as endocrine disrupting chemicals (e.g., phytosterol compounds are known to impact steroid function) with long-term negative consequences for reproductive functions and bone health (Diamanti-Kandarakis et al. 2009, Jeng 2014, Lorand et al. 2010, Roy et al. 2009). Thus, the choice of proteins in the diet, just as with lipids and carbohydrates, needs to be made, not only in the right quantities, but also from appropriate sources of the protein. And one must remember that no source comes without a cost when consuming at higher quantities.

**Integrating Concepts into the Class**

From the perspective of metabolism, we need to move beyond the oversimplification of only two types of reactions (i.e., catabolism and anabolism) forming the entirety of metabolism. While we can very easily present these ideas within lectures, the ability to integrate and explore the concepts will better serve the students. As such, there are several laboratory exercises, case studies, and group projects that can be used in teaching the interaction of nutrition with metabolism. For some examples, please see my webpage at https://sites.google.com/view/nutrition-and-metabolism/home). These activities can easily be completed by: evaluation of claims from *fad diets* based on fundamentals of metabolism and nutrient balance, calculations of BMR with comparison to diet and level activity based on the idea of the Caloric balance, relationship of the various equations to each other, examination of nutrient balance via dietary recall, and comparison of diet with principal tissues being recruited and requirements based on primary fuel sources or a need to recover from stresses encountered.

Additionally, one can have students evaluate how one can use the MET values from ergometers (treadmills, stationary cycles, stair steppers, elliptical runners) at the gym or fitness center or fitness trackers and heart rate monitors to evaluate Caloric expenditure relative to BMR. In this second component, students need to be reminded that these estimates are based on the amount of energy that was necessary to complete the exercise, typically through a conversion of either the total amount of energy used by the machine or in response to the heart rate response of the exerciser during the bout of exercise. Regardless of the approach, the focus of the student investigation should be on the integration of nutrition and metabolism to allow for better understanding of the principles of metabolism and nutrition as they relate to health. This will provide a more robust understanding of the nutrient balance required for proper tissue functions and maintaining homeostasis and allow them to be better prepared for their future roles in healthcare and medicine.
About the Author
James E Clark is an Assistant Professor in the Biology Department at Los Medanos College, teaching Human Anatomy and Physiology and Pre-Health courses. He has two decades of experience in education and sports medicine as a strength and conditioning coach and athletic trainer. James is involved with research related to the means by which exercise and diet modification are beneficial for changing health status and resolving issues of overfatness along with improving educational performance for students.

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A Farmer’s Fear: Ehrlichiosis, a Tick-borne Disease

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Abstract
Ehrlichiosis (Ehrlichia chaffeensis), a bacterial infection transmitted by ticks, and its complications are examined here in a case-based learning approach. This case scenario describes a person who was bitten by a tick while farming and the complications they experienced. Students are presented with a patient case scenario that entails a detailed assessment of the patient’s physical status, medical history, vital signs, laboratory values, and treatment methods so as to provide a complete picture of the pathophysiology of ehrlichiosis. This case scenario can be used to teach physiology or pathophysiology of infection and inflammation topics in clinical courses such as nursing, physician assistant, pharmacy, and other allied health programs.

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Key words: Ehrlichia chaffeensis, ehrlichiosis, pathophysiology, inflammation, infection, case-based learning

Introduction/Background
Teaching physiology to health professional students using lecture alone is not the most effective approach because students may find the subject vast, dry, and challenging due to innumerable factual details and complex mechanisms (Miller et al. 2013; Alaagib et al. 2019). Case-based learning (CBL), which utilizes clinical case scenarios to teach underlying physiological concepts, is a student-centered learning method that allows open-ended exploration of topics, encourages discussion, and offers a structured approach to clinical problem-solving (Srinivasan et al. 2007; Gade and Chari 2013). Compared to traditional lecture-based learning, CBL allows students to engage in learning activities, helps boost their confidence as well as test scores, and improves long-term memory (Latif 2014; McFee et al. 2018). The CBL method described here utilizes a team-based learning (TBL) strategy in order to promote peer interaction at multiple levels and enrich the students’ learning experience (Gopalan and Kist 2018).

The development of ehrlichiosis, a tick-borne disease, was written for the advanced physiology course offered in professional year I of the pharmacy curriculum at the St. Louis College of Pharmacy. This course was a five-credit course that consisted of three components: lecture (3 credits), laboratory (1 credit), and case discussion (1 credit). The lectures were 50-minute meetings, three times per week, with approximately 250 students. The laboratory sections were limited to 20 to 24 students in a two-hour block, once a week, where students performed hands-on physiology experiments. The case discussion sections involved 24 students (subdivided into groups of four) for a weekly two-hour session. Each case discussion session focused on one key physiology topic that was addressed in the lecture. For example, during pulmonary physiology lectures, the clinical case scenario would pertain to a lung-focused pathophysiology such as asthma, chronic bronchitis, or pneumothorax.

The use of a clinical scenario during the case discussion session of the course allowed students to apply their knowledge for a better understanding of a selected physiology topic. The ehrlichiosis case study served as an example of the CBL method in teaching infection and inflammation topics. Before this case study discussion, students received a lecture on inflammation that covered the causes of inflammation, the characteristics of acute and chronic inflammation, cellular and chemical components associated with inflammation, and step-by-step details of events during inflammation (Hall and Hall 2021). In preparation for the case discussion, students in their respective groups were expected to complete a set of homework questions over a few days following the lecture. The homework questions allowed students to not only apply knowledge from the lecture but also to access resources they found helpful in answering these questions. An individual assessment (individual readiness assessment test) was administered immediately prior to the case discussion.

The following ehrlichiosis case scenario would be an excellent resource for immunology, microbiology, or pathology classes in a biomedical science program or in medicine, nursing, or other health-related professions. In conclusion, the ehrlichiosis case could serve as a resource and an example of CBL while teaching infection and inflammation topics in a student-centered teaching method.

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Objectives
At the end of ehrlichiosis case study session, students would be able to:

- differentiate ehrlichiosis and other tick-borne diseases such as Lyme disease and Rocky Mountain Spotted Fever.
- characterize the vectors responsible for the transmission of mentioned diseases, including the distribution and natural reservoir.
- list the methods utilized to diagnose ehrlichiosis.
- describe clinical manifestations of ehrlichiosis, including immune response and morbidity and mortality rate.
- differentiate the treatment choices for ehrlichiosis and, in particular, the first-choice antibiotics.

Classroom Management
The students learned the basics of tick-borne diseases in multiple forms: 1) during class, 2) while answering the questions for the homework portion of the CBL, and 3) when applying their knowledge by discussing and solving a clinical case scenario on the topic. The lecture on inflammation included discussing the types of inflammation, causes of inflammation and their consequences, cellular and molecular components associated with inflammation, signs and symptoms, diagnosis, and treatment options (Hall and Hall 2021).

The steps to be completed by instructors and students in preparation for and during a typical case-based discussion session are described below and summarized in Table 1.

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Instructor Activities</th>
<th>Student Activities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Preparatory Session</td>
<td>a. Assign reading(s)</td>
<td>a. Complete reading assignment</td>
</tr>
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<td></td>
<td>b. Three 50-minute lecture sessions per week</td>
<td>b. Attend lecture session</td>
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<tr>
<td></td>
<td>c. Release homework questions with a due date by the start of the case discussion session</td>
<td>c. Submit answers to homework questions before the start of the case discussion session</td>
</tr>
<tr>
<td></td>
<td>d. Create an individual quiz over homework questions</td>
<td>d. Prepare for the homework-based quiz</td>
</tr>
<tr>
<td>In-class Case-Discussion Session</td>
<td>a. Review of quiz</td>
<td>a. Complete an individual quiz</td>
</tr>
<tr>
<td></td>
<td>b. Release of case</td>
<td>b. Answer questions as teams and submit answers</td>
</tr>
<tr>
<td></td>
<td>c. Review of case</td>
<td>c. Engage in review of the case</td>
</tr>
<tr>
<td></td>
<td>d. Case questions released</td>
<td>d. As groups, engage in organizing answers by discussing, using resources</td>
</tr>
<tr>
<td>Post-case Session</td>
<td>a. Grading of homework</td>
<td>Receive graded answers with comments</td>
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<tr>
<td></td>
<td>b. Assessment of team member participation in completing homework questions</td>
<td></td>
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<tr>
<td></td>
<td>c. Grading of teams’ answers pertaining to the case using a rubric</td>
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</table>

Table 1. Summary of Student and Instructor Roles in a Case Discussion Session
Homework

To prepare for the case discussion session, the instructor assigned homework questions (Appendix 1) as a group activity. These questions were designed to help review the background knowledge to complete the case study (quiz and in-class group questions). Students were given one week to complete homework questions and were expected to provide citations for the information submitted. The participation of all group members was expected. The students were expected to submit the completed assignment on the day of the case discussion before the scheduled session.

Case Session

To assess each student’s readiness level, a five-question quiz (individual readiness assessment test; Table 2) was given before the case was presented. Subsequently, questions and answers were reviewed with the students. Upon reviewing the quiz questions, students assembled in their respective groups. Each group of four students was formed early in the semester and remained unchanged for the entire course (Gopalan et al. 2013). The groups were formed utilizing multiple factors such as GPA, gender, and ethnicity to create the most heterogeneous groups possible (Gopalan et al. 2013).

1. _____ Ehrlichiosis is a
   a. viral infection.
   b. bacterial infection.
   c. fungal infection.
   d. none of the above.

2. Match the disease with the common tick species vector:
   _____ Rocky Mountain spotted fever a. American dog tick
   _____ Ehrlichiosis b. Lone star tick
   _____ Lyme disease c. Black-legged tick

3. _____ Which test or physical sign might help the health professional to most quickly diagnose ehrlichiosis?
   a. Polymerase chain reaction
   b. Blood smear
   c. Complete blood count
   d. Wide-spread skin rash

4. _____ The first-choice antibiotic for the treatment of ehrlichiosis is?
   a. tetracycline
   b. penicillin
   c. amoxicillin
   d. amphotericin B
   e. doxycycline

5. _____ Which lab values pertaining to blood cells or components are frequently elevated or depressed in ehrlichiosis?
   a. Leukopenia
   b. Thrombocytopenia
   c. Anemia (decreased hemoglobin and hematocrit)
   d. All choices are correct

Table 2. Individual Readiness Assessment Test and Answers

A copy of the case was distributed, and the instructor provided a brief introduction to the case scenario. Once students reviewed the case, the in-class discussion questions were released to the students one at a time. The students were encouraged to discuss the questions, look up the answers using available resources (textbooks, homework, peer-reviewed journals), and provide answers in essay form. During this period, the instructor was available to answer any questions and provide guidance. Approximately 20 to 30 minutes was allocated to each in-class question. One student from each group was expected to submit their group's answers by the end of the case session, including citations used to complete this assignment (team readiness assessment test).

Background Information Related to the Case
Before solving the ehrlichiosis case, students were expected to be familiar with white blood cells, types of white blood cells, and their functions.

Pathophysiology of Ehrlichiosis
Ehrlichiosis is a tick-borne disease predominately found in the Midwest and Southern USA, especially during the summer season (Dumler and Bakken 1995; Dumler et al. 2007; Gangulya and Mukhopadhayay 2008). It is caused by *Ehrlichia chaffeensis*, a gram-negative, obligatory intracellular, cholesterol-dependent bacterium that is incapable of aerobic metabolism (Dumler and Bakken 1995; Gangulya and Mukhopadhayay 2008; Rikihisa 2015). This bacterium causes damage to the host's defense system and there are two types of ehrlichiosis based on the leukocyte type that is affected (Rikihisa 2015). If the bacterium invades monocytes (a non-granular leukocyte), the disease is called human monocytic ehrlichiosis (HME), and if the bacterium invades a neutrophil (granular leukocyte), the disease is human granulocytic ehrlichiosis (HGE) (Dumler et al. 2007; Gangulya and Mukhopadhayay 2008).

Although the exact mechanism by which *E. chaffeensis* causes the disease in the human host is not fully understood, it appears that binding of *E. chaffeensis* to the cell membrane of monocytes triggers remodeling of cytoskeletal structures in order to promote engulfment. Once they are within the cell, they alter vesicular trafficking to avoid delivery to lysosomes. Furthermore, it appears that *E. chaffeensis* uses mechanisms to prevent damage to itself and to host cells (Rikihisa 2015).

Clinical Manifestations
Clinical manifestations of this disease include gastrointestinal disturbances (nausea, vomiting, diarrhea), fever, myalgia, headache, malaise, and a wide-spread rash (~30% of cases, but the rash is a late finding); other findings include leukopenia (low leukocyte count), thrombocytopenia (low platelets), and elevated liver enzymes (Paddock and Childs 2003; Dumler et al. 2007). To be noted, the liver is frequently (~80%) involved in the disease, but other organs such as the heart, lungs, brain, pancreas, gastrointestinal tract, or kidneys may also be affected (Paddock and Childs 2003). Destruction in immunologic tissues such as the liver and the spleen results in low levels of leukocytes and platelets (Paddock and Childs 2003; Kumar et al. 2015; Abbas et al. 2018). Cardiovascular, respiratory, and central nervous system complications can be severe; especially, with HME, which carries higher morbidity and fatality rates (Dumler et al. 2007).

Because of the risk of severe consequences from waiting for the definitive diagnosis, treatment should not be delayed (Dumler et al. 2007; Huntington et al. 2016). When presenting this case, it should be emphasized that many tick-borne diseases have similar presentations, including influenza-like and nonspecific signs and symptoms such as fever, headache, malaise, and myalgias (Bratton and Corey 2005; Huntington et al. 2016). Ehrlichiosis can be diagnosed via blood smear testing (Schotthoefer et al. 2013; Bakken and Dumler 2015).

The Case Study
In July, Bill, a 60-year-old farmer in Missouri, went to the emergency department (ED) of a city hospital after being referred by a walk-in medical clinic’s physician. An 18-gauge IV (intravenous) catheter was placed in his left forearm. A medical history was taken along with a physical examination and blood tests, as described below.

Bill’s Medical History
- Childhood infections of measles and mumps.
- Immunizations are up to date, including tetanus shots.
- Arthritis.
- Patient reported frequent tick bites despite using preventive measures, such as protective clothing and repellents.
- Used to smoke about one pack of cigarettes for a period of 5 years. He quit smoking 30 years ago.
- Family history:
  - Father died of lung cancer with a history of cigarette smoking.
- Medication
  - Meloxicam 15 mg once a day
  - Prednisone 5 mg once a day as needed
  - Sulfasalazine 1000 mg once a day
  - Simponi injection monthly
  - Melatonin 5 mg every night as needed for insomnia.
- Allergies: No known drug allergies.

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**Vital Signs**

<table>
<thead>
<tr>
<th>Objective Data</th>
<th>Vital Signs</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Blood Pressure</td>
<td>105/80 mm Hg</td>
<td>120/80 mm Hg</td>
</tr>
<tr>
<td>Pulse Pressure</td>
<td>25 mm Hg</td>
<td>40 mm Hg</td>
</tr>
<tr>
<td>Heart Rate</td>
<td>130 beats/minute</td>
<td>60-100 beats/minute</td>
</tr>
<tr>
<td>Respiratory Rate</td>
<td>36 breaths/minute</td>
<td>12-18 breaths/minute</td>
</tr>
<tr>
<td>O₂ Saturation</td>
<td>94%</td>
<td>95% on room air (21% FiO₂)</td>
</tr>
<tr>
<td>Body Temperature</td>
<td>39.4°C</td>
<td>36.1°C - 37.2°C</td>
</tr>
<tr>
<td>Body Mass Index</td>
<td>33.1 kg/m²</td>
<td>18.5 - 24.9 kg/m²</td>
</tr>
<tr>
<td>Height</td>
<td>5' 10”</td>
<td>5' 8” – 6’</td>
</tr>
<tr>
<td>Weight</td>
<td>200 lb</td>
<td>165 lb - 180 lb</td>
</tr>
</tbody>
</table>

**Physical Assessment**

Bill was alert, awake, and oriented to time, place, and location. Pupils were equal, round, and reactive to light and accommodation at 4 mm bilaterally. Pulses were present in all four extremities but were weak and rapid with a delayed capillary refill of three seconds. He was found to be febrile, dehydrated, and experiencing chills, malaise, and myalgia. He complained of anxiety, weakness, and headache but showed no signs of a rash. Breath sounds with some rales were noted. No heart murmurs were auscultated. Blood samples were obtained and sent to the laboratory.

**Laboratory Data**

Arterial blood gas (ABG) laboratory values

<table>
<thead>
<tr>
<th>ABG values</th>
<th>Lab Results</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>ABG pH</td>
<td>Within normal limit</td>
<td>7.35-7.45</td>
</tr>
<tr>
<td>PaCO₂</td>
<td>Within normal limit</td>
<td>35-45 mm Hg</td>
</tr>
<tr>
<td>PaO₂</td>
<td>Within normal limit</td>
<td>80-100 mm Hg (21% FiO₂)</td>
</tr>
<tr>
<td>FiO₂</td>
<td>Within normal limit</td>
<td>21% FiO₂ (Room Air)</td>
</tr>
</tbody>
</table>

Venous blood laboratory values

<table>
<thead>
<tr>
<th>Venous Values</th>
<th>Lab Results</th>
<th>Normal Values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolytes: K⁺, Cl⁻, Na⁺</td>
<td></td>
<td></td>
</tr>
<tr>
<td>K⁺</td>
<td>5.6 mEq/L</td>
<td>K⁺ (3.5-5.0 mEq/L),</td>
</tr>
<tr>
<td>Cl⁻</td>
<td>97 mEq/L</td>
<td>Cl⁻ (95-105 mEq/L)</td>
</tr>
<tr>
<td>Na⁺</td>
<td>128 mEq/L</td>
<td>Na⁺ (135-145 mEq/L)</td>
</tr>
<tr>
<td>Troponin-I Level</td>
<td>0.017 ng/L</td>
<td>0.000-0.049 ng/L</td>
</tr>
<tr>
<td>Liver Function Test</td>
<td></td>
<td></td>
</tr>
<tr>
<td>ALT/SGPT</td>
<td>84 U/L</td>
<td>ALT/SGPT (13-61 U/L)</td>
</tr>
<tr>
<td>AST/SGOT</td>
<td>111 U/L</td>
<td>AST/SGOT (5-40 U/L)</td>
</tr>
<tr>
<td>Complete Blood Count (Hemoglobin, Hematocrit, Platelets, WBC’s with differential)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hemoglobin</td>
<td>12.4 gm/dL</td>
<td>Hemoglobin (13-18 gm/dL)</td>
</tr>
<tr>
<td>Hematocrit</td>
<td>34.4%</td>
<td>Hematocrit (35.2-51.7%)</td>
</tr>
<tr>
<td>Platelets cells/mcL</td>
<td>73,000</td>
<td>Platelets (150,000-350,000 cells/mcL)</td>
</tr>
<tr>
<td>WBC cells/mcL</td>
<td>6700</td>
<td>WBC (5,000 -10,000 cells/mcL)</td>
</tr>
<tr>
<td>Neutrophils</td>
<td>80%</td>
<td>Neutrophils (44-73%)</td>
</tr>
<tr>
<td>Lymphocytes</td>
<td>1%</td>
<td>Lymphocytes (2-8%)</td>
</tr>
</tbody>
</table>

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Diagnostic Data

<table>
<thead>
<tr>
<th>Test</th>
<th>Result</th>
</tr>
</thead>
<tbody>
<tr>
<td>12-Lead EKG</td>
<td>Sinus tachycardia 130 beats per minute</td>
</tr>
<tr>
<td>Chest X-Ray</td>
<td>Perihilar infiltrates per anterior posterior and lateral chest films</td>
</tr>
<tr>
<td>Blood Smear with Staining (Wright's)</td>
<td>Demonstrated no bacteremia per microscope slides</td>
</tr>
<tr>
<td>Blood Cultures</td>
<td>Pending</td>
</tr>
<tr>
<td>Antibody Titers for a Variety of Tick-borne Diseases</td>
<td>Pending</td>
</tr>
</tbody>
</table>

Diagnosis

The ED physician suspected that Bill had contracted a tick-borne disease. Titers for Rocky Mountain spotted fever, ehrlichiosis, and Lyme disease were drawn and were pending.

Care Plan

Supportive measures to reduce fever was initiated along with regular patient monitoring. Started gentle fluid hydration with continuous 0.9% normal saline at 125 mL/hr. Began doxycycline administration, a treatment of choice for ehrlichiosis and all other tick-borne rickettsial diseases. Doxycycline is most effective at preventing severe complications if started within the first week of illness. Transferred to the medical ward for close observation until the patient’s condition stabilized. After discharge, continued doxycycline treatment and recommended follow-up with primary care physician.

Case Study Questions with Answers

1. Which symptoms, signs, and laboratory values are consistent with the diagnosis of ehrlichiosis and which ones are not?

   Possible symptoms include generally feeling poor, a marked fever, headache, chills, weakness, gastrointestinal disturbances such as nausea, diarrhea, and rash (non-itchy). Also, the symptoms develop slowly over one to two weeks, but once the infection is established, it progresses quickly. To be noted, many of the tick-borne diseases have similar presentations. A tick-borne disease should be considered in an individual during the warmer months of the year when that person is manifesting nonspecific, influenza-like signs and symptoms such as fever, headache, malaise, and myalgias.

   Thrombocytopenia, leukopenia (especially monocytes), and/or elevated liver enzyme levels are helpful predictors of ehrlichiosis, but may not be present in all patients depending on the course of the disease. After a diagnosis is made on clinical suspicion and treatment has begun, specialized laboratory testing should be used to confirm the diagnosis of ehrlichiosis. The PCR-based test results were positive for antibodies, which manifested later and confirmed the diagnosis in Bill.

   Treatment should begin immediately based upon suspicion of a tick-borne illness. Early treatment with doxycycline (or tetracycline) may substantially lower morbidity and mortality, and many of the tick-borne diseases (Rocky Mountain Spotted Fever, Lyme disease, tularemia, etc.) are sensitive to this antibiotic as the first line of treatment. With regard to the current case, the physical exam ruled out myocardial infarction (no murmurs, normal 12-lead, and normal Troponin I). The fever was related not only to interleukins and/or immune response but also to the fact that this organism behaves like mitochondria, producing excessive ATP (adenosine triphosphate). The elevated fever drives the metabolic rate, which is readily supported with excessive ATP. Electrolytes and dehydration status need to be maintained within normal limits to avoid cell membrane potential disturbances. To be noted, while perihilar lung infiltrates are consistent with the diagnosis, the patient has normal arterial blood gases and pH. Thus, at this point, the infiltrates have not caused a ventilation-perfusion mismatch to the degree needed to make the values abnormal.

2. Which values of a complete blood count and differential are typically elevated or depressed with a tick-borne illness?

   Although it varies from one tick-borne disease to another, the most common findings are decreased hematocrit due to hemolytic anemia, thrombocytopenia, leukopenia, elevated serum creatinine, and blood urea nitrogen values, and mildly elevated hepatic transaminase values.

3. What is the first choice of antibiotic for a tick-borne disease?

   Doxycycline and tetracycline are the treatments of choice for anaplasmosis, ehrlichiosis, and spotted fever group rickettsioses. Treatment may begin as soon as they are clinically confirmed because any delay may result in severe illness and even death.

4. What is the probable cause of the elevated liver enzymes?

   The liver is involved in >80% of all infected patients in ehrlichiosis. The underlying hepatic pathology is incompletely described and includes a variety of lesions ranging from focal hepatic necrosis to ring granulomas identical with those described in fever and cholestatic hepatitis. These findings suggest the induction of nonspecific mononuclear

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phagocyte activity and the potential for immunopathologic or cytokine-mediated hepatic injury as potential pathogenetic mechanisms. A few studies have described the microscopic pathological lesions and implied that the most dramatically involved organs are those of the mononuclear phagocyte system, especially the spleen, liver, bone marrow, and lymph nodes. Many other organs have perivascular lymphohistiocytic infiltrate, reflecting the systemic distribution of the infection, immune and inflammatory responses of the host, or a response to tissue injury due to the variable hemodynamics sometimes seen with ehrlichiosis (Ismail et al 2012). Immunohistologic studies have demonstrated that E. chaffeensis can establish infection in many organs and tissues; this characteristic is determined only by the presence of an appropriate phagocytic host cell. The lung is also a frequent target demonstrating interstitial pneumonitis, pulmonary hemorrhage, and diffuse alveolar damage with organizing pneumonia.

Conclusions
In summary, this case study can teach physiological and pathological concepts associated with bacterial infections transmitted by ticks. Students would be able to connect this case with what they have learned about inflammation, such as causes of inflammation and specific signs and symptoms associated with it. While becoming familiar with clinical terminology, students would be able to apply their knowledge of infection and inflammation by working on an ehrlichiosis case study with their group members.

About the Authors
Dr. Chaya Gopalan is a professor in the departments of Applied Health and Nurse Anesthesia at Southern Illinois University Edwardsville. She received her Ph.D. from the University of Glasgow, Scotland. She has been teaching anatomy, physiology, and pathophysiology at graduate and undergraduate levels. Dr. Gopalan practices evidence-based teaching using team-based learning, case-based learning, and the flipped classroom methods. She has received many teaching awards, including the Arthur C. Guyton Educator of the Year award from the American Physiological Society and the Outstanding Two-Year College Teaching award by the National Association of Biology Teachers.

Nhan Nguyen, RN, BSN is a candidate for Doctor of Nursing Practice specializing in Nurse Anesthesia at Southern Illinois University Edwardsville. He has served as a teaching assistant for the students in the Advanced Human Physiology course for the Doctor of Nursing Practice specializing in Nurse Practitioner program and the Biology of Cardiovascular and Metabolic Diseases course in the Exercise Science program.

Dr. William Kist is a physiology professor with strong clinical skills in respiratory physiology. He has written and published several cases as a way to teach physiology to students in the healthcare professions.

References


APPENDIX: Homework Questions and Answers

1. Compare and contrast the diseases Rocky Mountain spotted fever, Lyme disease, and ehrlichiosis in adults on signs, laboratory values, and symptoms. (reference for answers is Bratton and Corey 2005: 2325)

<table>
<thead>
<tr>
<th>Tickborne Disease</th>
<th>Signs and Symptoms</th>
<th>Lab tests</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rocky Mountain spotted fever</td>
<td>Fever, headache, nausea, vomiting, nonproductive cough, sore throat, pleuritic</td>
<td>Skin biopsy of rash (60 percent sensitive); routine findings include</td>
</tr>
<tr>
<td></td>
<td>chest pain (sudden sharp pain), abdominal pain, and petechial rash (small purple</td>
<td>thrombocytopenia (less than normal number of thrombocytes) and</td>
</tr>
<tr>
<td></td>
<td>or red rash) affecting pads and soles of feet, malaise (uneasiness), and myalgias</td>
<td>hyponatremia (less than normal sodium ion in the blood)</td>
</tr>
<tr>
<td></td>
<td>(muscle soreness)</td>
<td></td>
</tr>
<tr>
<td>Lyme disease</td>
<td>Stage 1 (early localized): erythema migrans rash (expanding rash) at the site of</td>
<td>Not helpful</td>
</tr>
<tr>
<td></td>
<td>the bite, flu-like symptoms, fever, fatigue, arthralgias (joint pain), headache,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>cough, lymphadenopathy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 2 (early disseminated): secondary cutaneous annular lesions, fever, adenopathy</td>
<td></td>
</tr>
<tr>
<td></td>
<td>central nervous system symptoms; possible cough and pharyngitis</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Stage 3 (late chronic): arthritis, central nervous system impairment, dermatitis,</td>
<td></td>
</tr>
<tr>
<td></td>
<td>keratitis, neurologic, and myocardial abnormalities</td>
<td></td>
</tr>
<tr>
<td>Ehrlichiosis</td>
<td>Flu-like symptoms, fever, chills, cough, malaise, headache, and myalgia; macular,</td>
<td>Leukopenia, thrombocytopenia, and elevated serum transaminase levels;</td>
</tr>
<tr>
<td></td>
<td>maculopapular, or petechial rash (rare with human granulocytic ehrlichiosis)</td>
<td>diagnosis made during the gradual recovery</td>
</tr>
</tbody>
</table>

2. Characterize and explain the tick vectors that are responsible for the transmission of these above diseases. What is the natural reservoir throughout the Midwest for these above diseases/organisms?

Children five to nine years of age have the highest incidence of Rocky Mountain spotted fever. A tick bite is recalled in 50 to 70 percent of patients. Rocky Mountain spotted fever is the most common rickettsial disease caused by *Rickettsia rickettsii* in the Midwest. Its reservoirs include small mammals such as rodents and rabbits, and dogs. Lyme disease is the most common vector-borne infectious disease in the United States. It is caused by the spirochete *Borrelia burgdorferi*. Vectors for this disease are black-legged or deer tick (*Ixodes scapularis*). The main reservoir for *B. burgdorferi* in the Midwest is the white-footed mouse. The larvae and nymphs of the tick feed on the white-footed mouse and become infected. Adult ticks or, more commonly, nymphs may then infect humans.

Human ehrlichiosis has been reported in the United States with two identifiable subtypes. Human monocytic ehrlichiosis (HME) is caused by *Ehrlichia chaffeensis*, and human granulocytic ehrlichiosis (HGE) is caused by *Anaplasma phagocytophilum* (formerly called *Ehrlichia equi* or *Ehrlichia phagocytophila*). The two subtypes are clinically indistinguishable but epidemiologically distinct. HME occurs most frequently in the south-central and southeastern United States. It occurs year-round, with the highest incidence in June and July. In contrast to Lyme disease and Rocky Mountain spotted fever, HME typically affects adults. *E. chaffeensis* is found in *Amblyomma americanum* (lone star tick) and *D. variabilis* (dog tick). The white-tailed deer is the principal animal reservoir.
3. **Describe the general immune response to a bacterial invasion including the inflammatory response.**

The immune response defends the host from bacterial invasion by using both innate and adaptive immune mechanisms. The innate immune response is the immediate response to infection. Pathogen-associated molecular patterns include bacterial lipopolysaccharides that bind to pattern recognition receptors on special immune cells such as macrophages and dendritic cells and turn on the inflammatory response.

In response to infection, one of the first groups of cells to respond are mast cells that release histamine. Histamine and other chemical agents released by the cells at the site of infection act on endothelial cells to increase capillary permeability so that more phagocytic leukocytes and plasma proteins crucial to the defense are recruited to the site of infection. Almost immediately, arterioles and capillaries within the area dilate, increasing blood flow to the site of infection. Local (resident) macrophages immediately begin to phagocytose foreign microbes, defending against infection during the first hour. Resident macrophages also secrete chemical mediators, which help recruit more leukocytes to the area. The recruited leukocytes are now activated by local chemical mediators, and these activated leukocytes tend to remove infectious agents and cellular debris by phagocytosis.

The leaked plasma proteins include clotting factors. On exposure to tissue thromboplastin in the injured tissue, fibrinogen, the final factor in the clotting system, is converted into fibrin. Fibrin forms clots in the spaces around the bacterial invaders and damaged cells. The walling off of the injured region from the surrounding tissues prevents or at least delays the spread of pathogens and their toxic products. The activation of the innate immune system ultimately turns on the adaptive immune system.

Dendritic cells process the antigen and present it to the helper T cells. Naive B lymphocytes may also process the pathogen and receive secondary signals from the helper T cells to differentiate into plasma cells and secrete antibodies. Acute-phase proteins such as complement proteins are activated by innate and adaptive immune mechanisms, which help promote opsonization and phagocytosis. The production of antibodies by the antibody-mediated immune system also uses opsonization and phagocytosis in addition to neutralization, precipitation, and other mechanisms to combat infection. Opsonized bacteria are engulfed and destroyed by phagocytes using mechanisms turned on by both antibody-mediated and cell-mediated immunity.

4. **What is the physiological connection between some tick-borne infections and mitochondria?**

Studies have shown that the host’s immune cells will generate reactive oxygen species (ROS) in response to some tick-borne infections. The predominant generator of ROS within the cells are the mitochondria. High levels of ROS create a toxic environment that can lead to damage of DNA, protein, and lipid and turn on the NF-kB pathway, which triggers the production of pro-inflammatory cytokines resulting in excessive inflammation and tissue injury (Peacock et al. 2015).

5. **How is the diagnosis of tick-borne illness confirmed? That is, which molecular biology technique is most useful in the differential diagnosis? Briefly describe the crux of how the technique works.**

Diagnostic tests include (a) examination of peripheral blood smears; (b) immunohistochemical staining of an organism from the skin, tissue, or bone marrow biopsies and (c) detection of DNA by PCR of whole blood. The PCR method uses specific oligonucleotide PCR primers based on nucleotide sequences of the pathogen and is very sensitive during the first week of illness. Sensitivity may decrease after tetracycline-class antibiotics treatment. Presence of morulae in the cytoplasm of granulocytes during the examination of blood smears is highly suggestive of a diagnosis.
6. Explain the general process of infection by ticks.

Ticks transmit pathogens that cause disease through the process of feeding. Depending on the tick species and their stage of life, preparing to feed can take ten minutes to two hours. When the tick finds a feeding spot, it grasps the skin and cuts into the surface. The tick then inserts its feeding tube. Many species also secrete a cement-like substance that keeps them firmly attached during the meal. The feeding tube can have barbs that help keep the tick in place. Ticks can also secrete small amounts of saliva with anesthetic properties so that the animal or person cannot feel that the tick has attached itself.

If the tick is in a sheltered spot (e.g., pubic region and hair) on the body, it can go unnoticed. A tick will feed on the blood slowly for several days. Small amounts of saliva from the tick may also enter the skin of the host animal during the feeding process. If the tick contains a pathogen, the organism may be transmitted to the host animal in this fashion. After feeding, most ticks will drop off and prepare for the next life stage. *Ehrlichia chaffeensis*, whose natural reservoir is the white-tailed deer, is generally transmitted to humans by the lone star tick (common in the state of Missouri).

7. Are different stages of the life cycle of ticks important/relevant to the infection process?

Most ticks go through four life stages: egg, six-legged larva, eight-legged nymph, and adult. After hatching from the eggs, ticks must ingest blood from a host body at every stage to survive. Thus, ticks can take up to three years and require several host bodies to become adults and complete their full life cycle; most die because they do not find a host for their next feed.

8. What is the morbidity and mortality rate of untreated tick-borne illnesses?

Certain types of tick-borne illnesses can cause deadly complications. Rocky Mountain spotted fever is the deadliest tick-borne disease in the world. Untreated Rocky Mountain spotted fever can cause damage to blood vessels, leading to organ and tissue injury (Centers for Disease Control and Prevention 2018).
Multimodal Review Sessions for Undergraduate Muscle Anatomy

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3 Corresponding author

Abstract
Engagement of multiple learning modalities has been shown to promote learning. This study aimed to develop resources for anatomical sciences educators interested in adding additional teaching modalities into their repertoire. Three review sessions were created for the muscle anatomy unit of an undergraduate anatomy and physiology course, each designed to engage a different learning modality. The first session was a kinesthetic experience in which students were cued through a sequence of body positions similar to yoga poses with instruction of muscle anatomy relevant to each position. The second session was a tactile experience in which students were instructed how to shape clay into models of muscles and place them on a corresponding plastic skeleton. The third session was an audience-response question and answer (Q&A) session in which students responded to questions and received feedback about their performance. Each of the three review sessions was successfully implemented in a large undergraduate course with 445 total students. The authors encourage other anatomy educators to adapt these sessions for use in their own teaching. https://doi.org/10.21692/haps.2021.022

Key words: multimodal, muscle, anatomy, kinesthetic, tactile

Introduction/Background
Learning science is a source of inspiration for educators who seek to better facilitate student learning and those who are interested in innovative educational approaches. In our anatomy program we became interested in the concept of learning modalities and the design of educational strategies utilizing non-traditional modalities. This paper details the theoretical basis of our investigation and how it led to our design and implementation of three muscle anatomy review sessions, each designed around different learning modalities.

In Mayer’s cognitive theory of multimedia learning, learning is defined as an active process of filtering, selecting, organizing, and integrating information based upon prior knowledge (Mayer 2009). This information is delivered to the learner through learning modalities, which Moreno and Mayer define as a “sense system used by which the learner receives [learning] material” (Moreno and Mayer 2007). The authors identify auditory and visual modalities, which correspond to the senses of hearing and sight, respectively. Moreno and Mayer go on to state that, “According to the modality principle of instructional design, the most effective learning environments are those that combine verbal and non-verbal representations of the knowledge using mixed-modality presentations” (Moreno and Mayer, 2007). The combination of visual and verbal information, i.e. a lecture slideshow with associated commentary, is the best described multimodal learning approach with the most evidence to its general effectiveness (Clark and Paivio 1991; Mayer and Sims 1994; Sadoski 2006).

Mayer’s cognitive theory of multimedia learning asserts that human working memory is informed by multiple sensory modalities, each of which has a limited capacity of processing information (Mayer 2005; Mayer et al. 2001). According to this theory, educators who engage multiple senses with non-redundant and non-overwhelming information can better engage working memory and promote better learning. Mayer focused on the dual channels of visual/pictorial and auditory/verbal processing in his research; however, the contribution of other sensory modalities to learning remains an open research area. Modality is used herein to indicate various avenues of content distribution apart from or in addition to visual (such as a digitally projected lecture slide) and apart from auditory (a lecturer vocalizing information) approaches.

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The physical and universal nature of anatomy makes it a topic well suited to incorporating modalities of student learning beyond the visual and auditory modalities typically engaged in lectures. All students of human anatomy possess a human body and experience that body through not only visual and verbal senses, but also through tactile sensation and proprioception. This common experience of an individual’s body is perhaps why innovative multimedia strategies for teaching anatomy abound. Sculpting or working with clay models (Bareither et al. 2013; DeHoff et al. 2011; Haspel et al. 2014; Kooloos et al. 2014; Oh et al. 2009; Waters et al. 2005), engaging in yoga/Pilates activities (Bentley and Pang 2012; McCulloch et al. 2010), body painting (McMenamin 2008), and engaging with virtual reality (Seo et al. 2017) are examples of innovative anatomy teaching strategies recently described in the educational literature.

A common theme to this innovative anatomy education literature is the engagement of proprioception and/or somatosensation to convey spatial information. Similar to a lecture format, these modalities can be delivered simultaneously with verbally-delivered auditory information. Delivering anatomical education using the multiple learning modalities with which we experience our own bodies may prove to have advantages over typical lectures including increased student engagement, efficient communication of nuanced physical relationships, and expanded associations of anatomical concepts and terminology. However, there is limited literature that describes the practical implementation of alternative learning modalities for anatomy for large (e.g. n>100) courses.

The authors undertook this pilot study in order to investigate the feasibility of applying these alternative modalities in an undergraduate anatomy and physiology course. Three review sessions of the same muscle anatomy unit, each designed to engage different sensory modalities, were implemented in a large undergraduate anatomy and physiology course following the lecture series that introduced muscle anatomy. Furthermore, outlines of the educational resources developed in this study are included as tables to enable their use and adaptation by anatomical sciences educators interested in incorporating multimodal sessions into their own teaching.

Methods

This study was performed as a part of a large (445 students) undergraduate anatomy and physiology course that included lecture and laboratory components. The majority of the study population consisted of first-year college students who were taking the course as a prerequisite for nursing school. The remaining enrollees in the course were students of kinesiology, health promotion, and pre-physical therapy majors. This study took place during the first semester of a two-semester anatomy and physiology sequence during the muscle anatomy unit.

Students pre-selected their preferred review session using a learning management system (Canvas, Instructure Inc., Salt Lake City, Utah) poll. The purpose of pre-selecting the activity of their choice was to give the instructors the opportunity to prepare appropriately-sized teaching space based on the estimated number of participants. The same instructor completed all three sessions of each modality; i.e. A.W. completed all three Q&A sessions, L.W. completed all three kinesthetic sessions, and K.P. completed all three tactile sessions. At the time, A.W. was a PhD candidate working as a teaching assistant in the course, L.W. was staff at the University otherwise unaffiliated with the course apart from this collaboration, and K.P. was an Assistant Professor and director of the course. No additional teaching assistants or other facilitators were involved.

The kinesthetic review session was held in a group exercise room in the campus recreation facility. Students were asked to wear clothing appropriate for the activity and were provided with a yoga mat that was loaned to them by the campus recreation facility. The instructor demonstrated movements at the front of the room, provided verbal cues for the movement, and verbally reviewed the muscles and attachments involved in the actions. Students followed along with the demonstrated movements and were encouraged to later study for the examination by reviewing the digitally provided review guide and recalling to memory and practicing the activities completed as a group. An outline of the movement sequence is provided in Table 1.
In the tactile experience, students were guided in shaping clay into models of muscles and placing them on a corresponding plastic skeleton, “Maniken” model ZSF-356 (Zahourek Systems Inc. and Affiliates, Loveland, CO). The instructor demonstrated creation of a specified muscle while discussing its proximal and distal attachments, as well as the actions of that muscle. Simultaneously, students began crafting their own clay versions of the same muscle, following along with the instructor. It was ultimately necessary that students worked in pairs due to the limited number (n = 18) of plastic skeleton models available. The session was held in a small lecture classroom with standard tables and the instructor moved throughout the room for the duration of the session while demonstrating the modeling of the muscles and helping students pinpoint attachments for the muscles on the plastic skeleton. Students were provided with a worksheet to guide their notetaking about each muscle. Table 2 shows an outline of the guided notes for the clay modeling.

<table>
<thead>
<tr>
<th>Region</th>
<th>Kinesthetic Movements</th>
<th>Muscles Verbally Reviewed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Muscles of Respiration</td>
<td>Chest breathing, Abdominal breathing</td>
<td>Diaphragm, intercostal muscles (external, internal, innermost)</td>
</tr>
<tr>
<td>Core</td>
<td>Twisting, Lateral flexion</td>
<td>Obliques (external and internal), transversus abdominis, multifidus</td>
</tr>
<tr>
<td>Scapula</td>
<td>Elevation, Depression, Retraction, Protraction, Stabilization</td>
<td>Trapezius, rhomboid, serratus anterior, pectoralis minor, levator scapulae</td>
</tr>
<tr>
<td>Rotator cuff</td>
<td>External and internal rotation</td>
<td>Supraspinatus, infraspinatus, teres minor, subscapularis</td>
</tr>
<tr>
<td>Sternocleidomastoid</td>
<td>Lateral Flexion, Rotation</td>
<td>Sternocleidomastoid</td>
</tr>
<tr>
<td>Shoulders</td>
<td>Flexion, Extension, Abduction, Adduction</td>
<td>Deltoid (three parts), pectoralis major, latissimus dorsi, coracobrachialis</td>
</tr>
<tr>
<td>Elbows</td>
<td>Flexion with supination and pronation, Resisted flexion, Resisted extension</td>
<td>Biceps brachii, brachialis, brachioradialis, triceps</td>
</tr>
<tr>
<td>Wrist and Digits</td>
<td>Wrist flexion and extension, Digit flexion and extension</td>
<td>“Flexor compartment”, “extensor compartment”</td>
</tr>
<tr>
<td>Spine</td>
<td>Flexion and extension in quadruped position (“Cat – Cow”)</td>
<td>Rectus abdominis, erector spiniae</td>
</tr>
<tr>
<td>Iliopsoas</td>
<td>Flexion, Stretch in Warrior I</td>
<td>Iliopsoas</td>
</tr>
<tr>
<td>Quadriceps</td>
<td>Knee Extension</td>
<td>Rectus femoris, vastus lateralis, vastus intermedius, vastus medialis</td>
</tr>
<tr>
<td>Hamstrings</td>
<td>Knee flexion, Stretch in laying position (Supta Padangusthasana)</td>
<td>Biceps femoris, semitendinosus, semimembranosus</td>
</tr>
<tr>
<td>Gluteal Muscles and</td>
<td>External rotation in Warrior I</td>
<td>Gluteus maximus, gluteus medius, gluteus minimus, sartorius</td>
</tr>
<tr>
<td>Sartorius</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Adductors</td>
<td>Wide leg standing</td>
<td>Adductor magnus, adductor longus, adductor brevis</td>
</tr>
<tr>
<td>External Rotators</td>
<td>Piriformis stretch</td>
<td>Piriformis, Superior and Inferior gemellus, obturator internus and externus, quadratus femoris</td>
</tr>
<tr>
<td>Feet</td>
<td>Flexion and extension of feet and digits</td>
<td>Tibialis anterior, gastrocnemius, soleus, digital flexors, “digital extensors”</td>
</tr>
<tr>
<td>Savasana + Synthesis</td>
<td>Lie in anatomical position</td>
<td>Review</td>
</tr>
</tbody>
</table>

Table 1: Summary of the content of the kinesthetic review.
The third review was an audience-response Q&A session in which students responded to questions digitally and received feedback about their performance. The Q&A session was held in the class lecture hall and consisted of a slideshow presentation created using Microsoft PowerPoint 2016 (version 16.0.4849.1000, Microsoft Corporation, Redmond, WA) with multiple-choice questions followed by slides with images of the relevant anatomy. Students were given time to read each question and select an answer independently using an audience-response remote polling system via their personal cellular devices (iClicker Cloud, formerly REEF, Macmillan Learning, New York, NY). Following the allotted time, the correct answer was revealed and the number of students who selected each possible answer was shown on-screen. This gave both students and the instructor feedback as to how many people selected the correct or incorrect answers. The instructor then explained the correct answer and the incorrect answers, with more time given to explaining questions with a lower percentage of correct responses. The information assessed in the review is summarized in Table 3.

<table>
<thead>
<tr>
<th>Muscle(s)</th>
<th>Proximal Attachment</th>
<th>Distal Attachment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erector Spinae</td>
<td>Inferior transverse processes of vertebrae</td>
<td>Superior transverse processes of vertebrae</td>
</tr>
<tr>
<td>Rotator Cuff (Supraspinatus, Infraspinatus, Teres minor Subscapularis)</td>
<td>Medial border of the scapula (superior to scapular spine, inferior to scapular spine, inferior to infraspinatus, anterior scapular surface)</td>
<td>Head of the humerus</td>
</tr>
<tr>
<td>Rhomboids</td>
<td>T2-T5 spinous processes</td>
<td>Medial border of the scapula</td>
</tr>
<tr>
<td>Teres Major</td>
<td>Inferior angle of the scapula</td>
<td>Proximal anterior humerus</td>
</tr>
<tr>
<td>Rectus Abdominis</td>
<td>Pubic symphysis</td>
<td>Xiphoid process and costal cartilage</td>
</tr>
<tr>
<td>Abdominal Obliques</td>
<td>Thoracolumbar fascia, inferior border of ribs</td>
<td>Iliac crest, inguinal ligament, linea semilunaris (continuing with aponeurosis to linea alba)</td>
</tr>
<tr>
<td>Latissimus Dorsi</td>
<td>Thoracolumbar fascia</td>
<td>Proximal anterior humerus</td>
</tr>
<tr>
<td>Trapezius</td>
<td>Nuchal ridge, C1-T2 spinous processes</td>
<td>Clavicle, acromion, and spine of the scapula</td>
</tr>
<tr>
<td>Gluteal Group</td>
<td>Posterior ilium, sacrum, and coccyx</td>
<td>Iliotibial tract and proximal posterior femur</td>
</tr>
<tr>
<td>Pectoralis Minor</td>
<td>Ribs 3-5</td>
<td>Coracoid process of the scapula</td>
</tr>
<tr>
<td>Pectoralis Major</td>
<td>Sternum</td>
<td>Proximal anterior humerus</td>
</tr>
<tr>
<td>Brachialis</td>
<td>Anterior distal humerus</td>
<td>Ulna</td>
</tr>
<tr>
<td>Coracobrachialis</td>
<td>Coracoid process</td>
<td>Proximal anterior humerus</td>
</tr>
<tr>
<td>Biceps Brachii</td>
<td>Coracoid process and supraglenoid tubercle of the scapula</td>
<td>Proximal radius</td>
</tr>
<tr>
<td>Triceps Brachii</td>
<td>Infraglenoid tubercle of scapula and posterior humerus</td>
<td>Olecranon process of the ulna</td>
</tr>
<tr>
<td>Deltoid</td>
<td>Clavicle, acromion, and spine of the scapula</td>
<td>Lateral proximal humerus</td>
</tr>
<tr>
<td>Forearm Flexors</td>
<td>Medial epicondyle of humerus and anterior radius + ulna</td>
<td>Anterior wrist and digits</td>
</tr>
<tr>
<td>Forearm Extensors</td>
<td>Lateral epicondyle of humerus and posterior radius + ulna</td>
<td>Posterior wrist and digits</td>
</tr>
<tr>
<td>Iliopsoas</td>
<td>Anterior transverse processes of T12-L4, Iliac crest</td>
<td>Lesser trochanter of femur</td>
</tr>
<tr>
<td>Adductor Group</td>
<td>Ischiopubic ramus</td>
<td>Medial border of femur</td>
</tr>
<tr>
<td>Quadriceps Femoris</td>
<td>ASIS and anterior femur</td>
<td>Tibia via patellar ligament</td>
</tr>
<tr>
<td>Sartorius</td>
<td>ASIS</td>
<td>Superior medial tibia</td>
</tr>
<tr>
<td>Hamstring Group</td>
<td>Iischial tuberosity and posterior femur</td>
<td>Tibia and fibula</td>
</tr>
<tr>
<td>Deep Posterior Leg Muscle Group</td>
<td>Posterior tibia</td>
<td>Ankle and plantar surface of foot</td>
</tr>
<tr>
<td>Soleus</td>
<td>Tibia and fibula</td>
<td>Calcaneus via Achilles tendon</td>
</tr>
<tr>
<td>Gastrocnemius</td>
<td>Medial and lateral condyle of femur</td>
<td>Calcaneus via Achilles tendon</td>
</tr>
<tr>
<td>Anterior Leg Muscle Group</td>
<td>Anterior tibia</td>
<td>Ankle and dorsal surface of foot</td>
</tr>
</tbody>
</table>

*Table 2: Summary of the guided notes page used during the tactile session.*
Multimodal Anatomy Review Sessions

These three review sessions were held simultaneously during the students' normal laboratory period. After each session, the same five-item quiz was given to students (referred to herein as the post-activity quiz). The quiz was developed by the session instructors in advance of the exercise, and the questions were targeted to the course skeletal muscle anatomy content that was emphasized in lecture. As the goal of the quiz was to capture any possible differences in foundational student knowledge, the questions were geared toward basic recall. Session attendance was assessed by totaling the number of completed quizzes.

Review effectiveness was assessed using the group mean score on the following three assessments: a post-activity quiz, overall performance on the following examination which included questions muscle anatomy and other topics, and performance on only the muscle anatomy examination questions (referred to herein as examination muscle question sub-score). These data were compiled using Microsoft Excel (version 16.0.4849.1000, Microsoft Corporation, Redmond, WA). Statistical analysis and visualization was performed using GraphPad Prism software (version 8.1.0, GraphPad Software Inc., San Diego, CA). Differences between Q&A, tactile, and kinesthetic group performance on each assessment were analyzed using one-way analysis of variance (ANOVA). One-way ANOVA was chosen because of the data set consisting of three sets of discrete values (for example, post-activity quiz scores for the Q&A group, the kinesthetic group, and the tactile group were compared). Differences were considered statistically significant if \( p < 0.05 \).

### Table 3: Summary of the question stems and the correct answers used for the multiple-choice Q&A review session.

<table>
<thead>
<tr>
<th>Question</th>
<th>Correct Answer</th>
</tr>
</thead>
<tbody>
<tr>
<td>Which of the following muscles causes flexion of the spine?</td>
<td>Rectus abdominis</td>
</tr>
<tr>
<td>Which of the following muscles causes lateral flexion of the spine?</td>
<td>Abdominal obliques and Erector spinae</td>
</tr>
<tr>
<td>Which of the following causes extension of the spine?</td>
<td>Erector spinae</td>
</tr>
<tr>
<td>Which of the following is an action of the latissimus dorsi?</td>
<td>Adduction at the shoulder</td>
</tr>
<tr>
<td>What is the proximal attachment of the teres major?</td>
<td>Scapula</td>
</tr>
<tr>
<td>Which of the following is NOT an action of the trapezius?</td>
<td>Protraction of the scapula</td>
</tr>
<tr>
<td>Which of the following muscles is responsible for abduction of the hip?</td>
<td>Gluteus maximus</td>
</tr>
<tr>
<td>Identify the indicated muscle(s)</td>
<td>Trapezius</td>
</tr>
<tr>
<td>Which of the following muscles does NOT attach to the skull?</td>
<td>Levator scapulae</td>
</tr>
<tr>
<td>Which of the following muscles attaches proximally to the humerus?</td>
<td>Brachioradialis</td>
</tr>
<tr>
<td>Which of the following muscle is responsible for flexion at the elbow?</td>
<td>Biceps brachii, brachialis, and brachioradialis</td>
</tr>
<tr>
<td>Which of the following is the proximal attachment of the hamstrings?</td>
<td>Ischium and femur</td>
</tr>
<tr>
<td>Which of the following muscles dorsiflexes the foot?</td>
<td>Gastrocnemius and soleus</td>
</tr>
<tr>
<td>Identify the indicated muscle(s)</td>
<td>Triceps brachii</td>
</tr>
<tr>
<td>Identify the indicated muscle(s)</td>
<td>Wrist extensors</td>
</tr>
<tr>
<td>Which of the following muscles is responsible for flexion at the shoulder?</td>
<td>Deltoid</td>
</tr>
<tr>
<td>What is the action of the sartorius muscle?</td>
<td>External rotation of the lower limb</td>
</tr>
<tr>
<td>What is the action of the rhomboids?</td>
<td>Retraction of the scapula</td>
</tr>
<tr>
<td>What is the proper order of muscles from superficial to deep?</td>
<td>Trapezius, rhomboids, and erector spinae</td>
</tr>
<tr>
<td>A 16 y/o African American girl presents to the emergency room with her parents. She had been competing in a gymnastic competition when she stuck a particularly challenging sideways landing, then collapsed. She points to her groin, saying that she felt a tearing there and it now hurts too much to walk. Which of the following muscle groups most likely related to this girl's pain?</td>
<td>Adductors</td>
</tr>
<tr>
<td>A 33 y/o Costa Rican man presents to a sports medicine clinic. He says that his right shoulder has been hurting him ever since his minor league baseball pitching career. He says that the pain is worse when he first lifts his arm, or when he tries to scratch his back. Which of the following muscle groups is most likely related to this man's pain?</td>
<td>Rotator cuff</td>
</tr>
</tbody>
</table>
This study was approved with exempt status by the University of Kentucky Institutional Review Board (IRB) on account of being limited to traditional classroom activities with minimal risk for participants, Protocol No. 16-0796-X1B, titled “Self-selected kinesthetic, tactile, or question-based learning modalities and their impact on examination performance.” Only students who signed informed consent documentation (n = 345) were included in this study. The remainder of the students enrolled in the course (n=100) were still required to participate in the multimodal session of their choice, as it was serving as one of their laboratory sessions, but were excluded from any data collection or subsequent analysis. Students who did not participate in any session lost the points associated with the weekly laboratory assignment (fifteen points out of 497 possible for the course; 3% of course grade). Study personnel (A.W., L.W., and K.P.) were trained in human subject protection per University of Kentucky Office of Research Integrity protocols.

**Results**

**Participation**

A total of 345 students consented to and participated in the study. Session participation was as follows: Q&A n = 180 (52.2%), Tactile n = 99 (28.7%), and Kinesthetic n = 66 (19.1%). This total number of participants was divided over three laboratory sections, each allotted up to one hour and fifty minutes, less time for the quiz. Total attendance at each session ranged from 81-93 per Q&A session, 39-40 per tactile session, and 25-35 per kinesthetic session.

The overall reliability of the quiz as a testing instrument was extrapolated by averaging the Kuder-Richardson (KR) Reliability Index for the three output groups. The KR for the quiz based on this approach is 0.19. The KR for the instrument group by group is: 0.26 for the Q&A group, 0.09 for the tactile clay group, and 0.21 for the kinesthetic group. Interestingly, the Discrimination Index (DI) for each of the quiz questions varied by group. In brief, the DI for question 1 was highest in the Q&A group and lowest in the Kinesthetic group, the DI for question 4 was consistently very high across the groups, middling for question 5, and variable for questions 2 and 3.

**Assessment Performance**

There was no significant difference in student performance on any of the three assessments (total examination score (p=0.59), examination muscle question subscore (p=0.15), or post-activity quiz score (p=0.46)) as assessed by one-way ANOVA. Figure 1 summarizes these results. The examination scores were 71.6% ± 13.6% for Q&A, 72.4% ± 14.1% for the tactile group, and 70.1% ± 13.1% for the kinesthetic group (F = 0.33, p=0.59). For the post-activity quiz score, performance out of 5 points possible was 3.3 (Q&A group), 3.3 (tactile group), and 3.5 (kinesthetic group) (F=0.78, p=0.46). Similarly, examination muscle question sub-score did not significantly vary between groups (65.4% ± 18.3% for the Q&A group, 67.7% ± 18.3% for the tactile group, and 66.7% ± 17.1% for the kinesthetic group; F=0.33, p=0.72).

![Figure 1: Comparison of total examination scores, examination muscle question subscores, and post-activity quiz scores based on review session attended (Q&A, Tactile or Kinesthetic).](image-url)
Discussion

This pilot study was successful in developing and implementing three different review sessions, each designed to engage a different sensory modality for learning muscle anatomy. Details for each section are discussed in the Implementation Feasibility section below. As a research study this work had several significant limitations, namely student self-selection and the lack of a pre-test. These factors are discussed in further detail in the Limitations section. In light of these limitations the study cannot draw firm conclusions from the performance data as to the efficacy of these sessions.

The authors are of the opinion that presenting information in multiple modalities to all students is generally the best educational approach. Due to the limitations of implementing this study during the scheduled course hours, it was not feasible to allow students to attend multiple review sessions. Nonetheless, it would be of great interest to the authors to study how providing multiple review sessions using different modalities to address the same content topic would affect student learning outcomes. Likewise, the simultaneous delivery of information through multiple modalities is also of interest. The principle of dual coding, which is widely accepted in educational literature (Pashler et al. 2008), predicts that all learners should benefit if visual information is layered over linguistic information. Does this principle hold true for the simultaneous delivery of kinesthetic and linguistic information, tactile and visual information, or even combinations of more than two modalities for learning appropriate subjects? Answering these questions may inform future evidence-based curriculum design.

This study asked students to indicate their preferred review session, each structured around a different learning modality. However, this study did not address student’s generally preferred learning style. Well-controlled studies looking at student learning style preferences have failed to show that a student’s preferred learning style is more effective for promoting learning in that student, independent of subject (Constantinidou and Baker 2002; Cook 2012; Cuevas and Dawson 2017; Husmann and O’Loughlin 2019; Knoll et al. 2017; Krätzig and Arbuthnott 2006; Massa and Mayer 2006; Rogowsky et al. 2015). In fact, various studies now directly question the actual impact, importance, and effect of targeting learning styles as a means to enhance student outcomes (Cook, 2012; Husmann and O’Loughlin 2019). For a complete review, see (Cuevas 2015; Pashler et al. 2008). Instead, perhaps certain subjects are better suited to incorporating different learning styles into their teaching and learning methodology. This study suggests that while not all subjects can cater to preferred learning approaches, anatomy is an appropriate subject for developing kinesthetic and tactile learning curricula.

Implementation Feasibility

This study was executed during a typical undergraduate course, demonstrating the feasibility of implementing these educational sessions with appropriate resources and support, even for large numbers. These review sessions were conducted without cadavers, ultrasound machines, or specialized digital tools that other anatomy education approaches may require (Estai and Bunt 2016; Griksaitis et al. 2012). While the above tools offer great value for anatomy education, they are not always available, the local budget may not allow their application, nor are they always conducive to use in large groups. The large number of students enrolled in the course (445, including students who did not consent to participate in the study), did make it a challenge to create interactive sessions that could accommodate all participants. Smaller groups would allow more individual attention for students and would alleviate many space and resource constraints. Also of note, nearly half (n=165, 47.8%) of the study participants preferred to attend a tactile or kinesthetic review session to an audience-response Q&A review of muscle anatomy when given the choice. This desire for alternate learning environments highlights the demand for multimodal anatomy curricula, especially with evidence that alternative modalities are effective in communicating anatomy information.

The kinesthetic session, while novel and exciting, posed a number of challenges. A vital consideration for holding an institution-approved kinesthetic session was taking proper safety precautions. L.W., the author who led the kinesthetic sessions, is a licensed and insured yoga instructor with experience leading groups with a spectrum of physical fitness levels from young, fit individuals to less active, elderly individuals. Space considerations include a room large enough to hold all participants, ideally somewhat private, with access to mats or other surfaces for standing, sitting, and laying down.

For the tactile session utilizing clay modeling on plastic skeletons, instructors considering using a similar approach must be aware of the resource burden and space requirements. For example, funds must be secured to purchase the modeling clay and skeletons. If the instructor only has access to a few skeletal models, then this limits the number of students who can learn from the approach by a truly tactile method. Some students also may not prefer to handle the clay and, without appropriate work mats and student care for tidiness, soiling of the classroom surfaces is possible.

The Q&A session is the most traditional review session in this study. Audience-response systems are common in higher education (Alexander et al. 2009; Marenco et al. 2010) and the Q&A session used multiple-choice questions similar to those used for their examinations. When this study was conducted, all students in the course were required to purchase the

continued on next page
It is possible that student performance may not have the pre-review session knowledge of muscle anatomy. Furthermore, because students self-selected their review session modality, there is potential for selection bias in the session knowledge differentially. Perhaps the alternate modalities would reinforce higher-order knowledge that could not be measured with the post-activity quiz or muscle anatomy questions on the examination (referred to here as examination muscle question subscore). Both of these possibilities could be assessed in future work using a pre-test / post-test methodology in which students were given an assessment before the review session to compare their anatomy knowledge before and after the reviews.

This study is limited by lack of control in the form of pre-review session knowledge of muscle anatomy between groups. Without a pre-test assessing muscle anatomy knowledge prior to the review sessions this study cannot conclusively show that muscle anatomy knowledge was equivalent between different review sessions prior to the session. A follow-up study would incorporate a pre-test methodology to ascertain the study population's muscle anatomy knowledge prior to the interventions. In addition, it would be of interest to test the student participants with a quiz focusing on higher-order questions per Bloom's Taxonomy. While the current work found no differences in performance on basic recall-level questions, perhaps the alternate modalities would reinforce higher-order knowledge differentially.

In addition, because students self-selected their review session modality, there is potential for selection bias in the pre-review session knowledge of muscle anatomy. It is possible that student performance may not have been equal if students were randomly assigned to a review other than their preferred session. The authors do note that the intention of this research is to investigate alternative methods of education that may be more effective for students based on increased engagement. If students were randomly assigned to a review other than their preferred session then the majority would not be placed in their preferred session, and this may have led to decreased student engagement. The authors considered a follow-up study in which the review session groups were assigned instead of self-selected but have not yet pursued such project. An appropriate study design would directly investigate this effect by randomizing part of the cohort while allowing the remainder of students to choose their session and comparing student performance and markers of engagement.

Finally, the current study has no means to measure the qualitative value, or lack thereof, regarding the multimodal approaches. As anatomy is a topic that is very physical and universal in its nature, since all humans have a human body, exploring it through various interactive means seems logical. The intrinsic value of these alternate approaches may be more abstract and, therefore, difficult to measure through basic recall. Future studies would do well to include qualitative measures of student learning, growth, and engagement to explore these possible markers of the approaches’ value.

**Conclusion**

This study explored multimodal methods for teaching muscle anatomy by developing and implementing three review sessions: a question-and-answer review using audience-response technology, a tactile review using clay modeling, and a kinesthetic review using guided movement sequenced similar to yoga. Materials used in these review sessions are provided so that they may be adapted by anatomy educators for their own needs. The authors encourage educators to use these and other educational approaches in combination, as engaging multiple learning modalities is beneficial for all students.

**About the Authors**

Andrew Welleford is an MD-PhD student at the University of Kentucky College of Medicine. His research interests include medical sciences education and neurodegenerative disease.

Lauren Weaver, B.S. is a certified Geographic Information Systems Professional and master’s student in Information Communication Technology. She seeks to help others acquire an understanding of their own minds and bodies.

Kristen Platt is an assistant professor in the Department of Neuroscience at the University of Kentucky College of Medicine. Her scholarship interests are the areas of education best practices and the medical humanities.
References


Students Work in Groups to Create and Peer-Evaluate Newsletters Pertaining to Current Health-Related Topics

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Abstract
A challenge with large undergraduate classes is the provision of opportunities for students to construct educational documents and to obtain individualized feedback pertaining to their work. Being able to work as part of a group, to clearly express information both orally and in writing, and to self-reflect while providing constructive feedback are soft skills that are valued by employers in the healthcare professions. We describe a two-part assignment in which students first worked in small groups to construct an informative newsletter pertaining to either the gut microbiome or one of four assigned fad diets and then evaluated a newsletter created by a group of their peers. Survey data revealed that most students found the assignments valuable learning exercises and that the opportunity to evaluate a newsletter created by their peers was welcomed. These assignments provide a way for students studying anatomy and physiology to reflect on what they have learned in class and, through self-directed research, apply their new knowledge in a way that will serve them well once out in the workplace.  
https://doi.org/10.21692/haps.2021.010

Key words: assignment, communication, soft skills, peer-evaluation, large classes, health sciences

Introduction
We have previously reported the use of creative online assignments to encourage the development of communication skills in nursing students studying anatomy and physiology. These initial assignments asked each of them to apply their newly acquired understanding of the immune system to the creation of an informative vaccination brochure targeting the general public (Savory and Carnegie 2019). In the current paper, we describe steps we have taken over the past three years to modify and extend these assignments so that students can explore other timely health-related topics while gaining additional experience associated with working in small groups to create their final product. We have also incorporated an opportunity to learn from the work of others in their class through the process of rubric-guided peer evaluation.

Often categorized as "soft skills" (Ray and Overman 2014), the development of strong oral and written communication skills is important for nursing students and other healthcare workers and should be encouraged wherever possible as they proceed through their undergraduate studies (Andre and Graves 2013; Feltham and Krahn 2016). Once Bachelor of Science in Nursing (BScN) graduates are in the workplace, this communication can take different forms. Orally, it can be the provision of clear and understandable explanations to patients regarding their healthcare, but it may also involve discussions among a team of healthcare professionals as they collaborate to meet all aspects of patient care (American Nurses Association 2010; Schwartz et al. 2019; Suter et al. 2009). Written communication can vary from keeping concise and accurate records of the vital signs and disease symptoms of hospital patients to the more complex demands of developing patient-targeted public health documents pertaining to illnesses and their management.

Studies have shown that group work, a form of active learning used at all levels of education, can enable learning, promote social interaction, and provide students with important collaborative skills, including conflict management, that will serve them well once they are out in the workplace (Burke 2011; Chiriac 2014; Murphy et al. 2005). For example, by providing a forum for discussion, group work has been shown to facilitate learning and foster the development of higher level critical thinking abilities as students interact with one another to share ideas, ask questions, and problem-solve while planning their finished product (Blowers 2010; Chiriac 2014; Gillies and Boyle 2011; Koh and Hill 2009). It has also been suggested that working as part of a group can provide extra motivation for engagement leading to higher levels of satisfaction with the task at hand and improved academic achievement compared to completing a project alone (Burke 2011; Chiriac 2014; Gillies 2003). Finally, an important recruitment asset valued by many employers, including those in the field of healthcare, is the ability to work as part of a team (Babiker 2014; Brennan et al. 2021; Chapman et al. 2006; Wu et al. 2014).

While group work often occurs in a face-to-face environment, a special case of group work occurs online. In this instance, because students connect with one another electronically via their course learning platform, they can have different
geographical locations, even live in different time zones, while still sharing ideas and reflecting on their assigned project. Studies looking specifically at online group work have proposed that in-depth processing and understanding of information and critical thinking occur in response to idea sharing and reflection as the students plan their approach to the assignment (Koh and Hill 2009; Wright and Lawson 2005). While the asynchronous nature of interactions that occur online has the potential to slow progress in planning, it also has the benefit of promoting reflection by allowing students to take time to think and organize their thoughts before responding to their peers (Koh and Hill 2009; Petrides 2002; Vonderwell 2003). Finally, student-student online interactions within the confines of assignment-associated small groups can foster a sense of community to help ground first-year students as they embark on distance learning within large undergraduate classes (Wright and Lawson 2005).

Peer assessment is an important component of active learning that is increasingly used to provide opportunities for students to develop valuable soft skills that are transferable to the workplace (Adachi et al. 2018; Li et al. 2016). These include the abilities to evaluate the qualities and accuracy of completed product, to think critically as they link what they are assessing with their own understanding of the topic, and to communicate clearly when providing constructive feedback to fellow students in the form of written justifications of assigned assessment scores (Adachi et al. 2018; Reinholz 2016).

This paper describes two types of newsletter assignments in which students began by collaborating online within small groups to create a product and finished by assessing a newsletter created by a group of their peers. The benefits of this constructive learning approach are discussed along with adjustments made to assignment design in response to student feedback. Challenges associated with managing the various aspects of the newsletter assignments in the context of large classes of undergraduate students are also addressed.

**Methods**

*Gut Biome Newsletter Assignment Part 1: Newsletter Creation*

This assignment was first given to students enrolled in two different sections of the same A&P course, ANP1107A (n = 291) and ANP1107B (n = 253) during the winter term of 2019. ANP1107 (Human Anatomy and Physiology III) is a 3-credit course that targets the endocrine regulation of metabolism and body temperature as well as the anatomy and physiology of the digestive, immune, renal, and reproductive systems. Approximately 50% of each class was composed of nursing students with most of the remaining students registered in other health science and medical science programs. Prerequisites for these programs include grade 12 biology and chemistry and the majority of students would also have completed ANP1105, an introductory ANP course that includes such topics as body tissues and the regulation of homeostasis by the autonomic nervous and endocrine systems. In this course, the first body system to be addressed is the digestive system and students were given the assignment only after the digestive system had been completely covered in lecture so that they would have an appropriate knowledge base upon which to build as they wrote their newsletter articles.

Within Brightspace (the learning management system [LMS] used by the University of Ottawa), students were randomly assigned to 5-member newsletter creation groups, with each group having its own private discussion folder. Students were provided with a list of suggested topics they could include in their two-page newsletter (Table 1) and given complete freedom to decide which member of their group would be the editor and to allocate among themselves (including the editor) the topics they would address with their newsletter. Students were given guidance as to maximum suggested word length per article (200 words), minimum font size (11 pt.), and the targeted audience (lay public – for example this could be a brochure available in their family doctor’s office) for their newsletter.

- A letter from the editor providing basic background information about gut microbiome, their importance, how the populations have changed over time, even a couple of fun facts or introducing probiotics
- News flash update with educational details about something very new pertaining to the gut microbiome
- Gut biome and weight management
- Gut biome and gut sensitivity
- Gut bacteria and overuse of antibiotics
- Gut biome and food allergies
- Gut biome and the brain
- Fecal transplants
- Effect of diet on gut microbiome populations

**Table 1.** Suggested Possible Subtopics for Gut Biome Newsletter from which Each Author could Choose.

The editor was responsible for setting a deadline for receipt of newsletter contributions, incorporating all article submissions into a 2-page newsletter in which each author’s contribution was linked with their name and student number, and removing any repetition between individual submissions in order to create a streamlined final product. Supportive illustrations, with appropriate citation, could be used as deemed necessary, and editors were encouraged to use formatting that would create an engaging and interest-grabbing document. Finally, editors were responsible for submitting their group’s assignment (newsletter plus a separate page with the authors’ references) within the Brightspace assignment folder by the due date. Students were given 4 weeks between the date of assignment posting and the deadline for newsletter submission.

[continued on next page]
Students Work in Groups to Create and Peer-Evaluate Newsletters Pertaining to Current Health-Related Topics

*Gut Biome Newsletter Assignment Part 2: Peer Assessment*

Following receipt of the newsletters, each instructor (J. Carnegie for ANP1107A and J. Savory for ANP1107B) then prepared them for anonymous peer review. The newsletters were redacted to remove all student names and numbers and resaved under a modified heading so that each one could then be sent via the private, small-group discussion folders to a different group for peer assessment.

Students were provided with a rubric (Table 2) to guide the completion of their peer reviews. In addition to scoring (fractions permitted) for four newsletter criteria (ability to engage the reader, accuracy, educational value, and overall impression), students were asked to briefly defend each score with a sentence or two of justification. The rubric also included two open-ended questions where they could highlight what they liked about the newsletter and indicate suggestions for improvement.

The editors were not required to provide a peer review, but, rather, were responsible for collating the reviews completed by the other group members into a single document to be submitted by the deadline. Students had 2 weeks to complete all steps of the peer assessment portion of the assignment.

Each student earned up to 4% of their final grade during the newsletter creation part of the project and a further 1% by completing a thoughtful peer assessment. Using the assignment grading function of Brightspace and guided by the same rubric provided to students to conduct their peer assessments, the authors provided each group with a score plus constructive feedback that addressed the strengths and weaknesses of each newsletter component (or the editorial work) and a separate grade with feedback for the peer assessments.

*Fad Diet Newsletter Assignment Part 1: Newsletter Creation*

This new assignment replaced the gut biome assignment for students enrolled in ANP1107A (n = 370) and ANP1107B (n = 278) during the winter term of 2021. Again, approximately 50% of students were enrolled in the BScN program with most of the other students studying in related fields linked to medical and health sciences. While many aspects of the assignment were the same, some important modifications were made to the design in response to survey feedback collected from students who completed the gut biome newsletter assignment two years prior. For this assignment, students were randomly divided into groups of six and each group was assigned one of four fad diets (Table 3) for their newsletter that was, again, to be directed toward the lay public.

<table>
<thead>
<tr>
<th>Evaluation Criterion</th>
<th>Score (3)</th>
<th>Justification of score given</th>
</tr>
</thead>
<tbody>
<tr>
<td>Ability to grab attention &amp; maintain interest</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Accuracy of information presented</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Educational value</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Overall impression</td>
<td></td>
<td></td>
</tr>
<tr>
<td>What I really liked</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Suggestions for improvement</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 2. Rubric used by Students for Peer Review of Gut Biome and Fad Diet Newsletters.

<table>
<thead>
<tr>
<th>Fad Diet (Assigned by Group Number)</th>
<th>Newsletter Subtopics</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Keto Diet</strong></td>
<td>1. Fad diets – why are they now so popular? What are some of the reasons why people are trying them?</td>
</tr>
<tr>
<td><strong>Gluten-Free Diet</strong> (when you don’t have Celiac Disease)</td>
<td>2. A brief description of your assigned fad diet and what it promises.</td>
</tr>
<tr>
<td><strong>Intermittent Fasting</strong></td>
<td>3. The physiology behind your fad diet – does the physiology support the diet claims?</td>
</tr>
<tr>
<td><strong>Paleo Diet</strong></td>
<td>4. Identify important nutrients that might be lacking in your assigned fad diet. Suggest how those deficiencies should be handled.</td>
</tr>
<tr>
<td></td>
<td>5. Does your fad diet offer any other benefits besides weight loss? How likely is long-term adherence to the fad diet? Why or why not?</td>
</tr>
</tbody>
</table>

Table 3. Assigned Fad Diets and Fad Diet Newsletter Subtopics
Groups were given freedom to choose their editor and the assigned subtopic (Table 3) that each of the remaining five group members would tackle with their submissions. For this assignment, editors were not required to write an article; their sole duty was to compile the finished product. Newsletter authors worked with the same suggested word length and maximum font size but were also provided with two firm due dates set by the instructors, rather than the editors. The first was the date by which they had to check in with their group to participate in task allocation so that the project could move forward and the second was the date by which they had to deliver their completed articles to the editor in order to ensure inclusion in the newsletter. The peer review process and the overall grading of newsletters and peer reviews were handled exactly as for the gut biome newsletter assignment.

**HAPS Learning Outcomes**

With regard to HAPS Learning Outcomes, the gut microbiome newsletter assignment builds on the A&P Digestive System Learning Outcome, Module N: 12.5: “Describe the role of bacteria (microbiome) in digestion.” The fad diet newsletter assignment links to several A&P Nutrients and Metabolism Learning Outcomes from Module O, including:

1.1 Define nutrient, essential nutrient, and non-essential nutrient.

1.2 Describe common uses in the body for carbohydrates, fats and proteins.

2.1 Define metabolism, anabolism, and catabolism, and provide examples of anabolic and catabolic reactions.

3.6 Compare and contrast carbohydrate, fat, and protein metabolism in the fed (absorptive) and fasted (post-absorptive) states.

**Collection of Student Survey Data**

At the end of the course, feedback was collected anonymously using a questionnaire composed of eight 5-point Likert-based questions plus two open-ended questions allowing students to identify what they liked or did not like about the assignment. Each survey also included a final, open-ended question directed at only the editors to collect feedback. The questions were designed to explore student perceptions regarding the learning value of the assignment (including opportunities for creativity and development of communication skills), the clarity of the instructions, and their attitudes toward group work and peer assessment.

In 2021, two of the Likert-based questions were modified to explore the ability of group work to promote welcome interactions with peers during a time of pandemic-induced studying in isolation as well as to collect student feedback about evaluating a newsletter about a fad diet that was different than the diet explored by their group. In 2019, students in both ANP1107A and ANP1107B were provided with the survey as a single page document with the option to complete it, if they chose to do so, at the time that they were writing their final exam. In 2021, given the pandemic and the complexities associated with the move to online learning, students in ANP1107A, only, were provided with the anonymous survey via Brightspace once the course had finished and, again, they were assured that survey completion was voluntary and anonymous. This project was approved by the University of Ottawa Human Ethics Committee (File number H09-06-10B).

**Results**

Even though the newsletter assignment, in total, represented only 5% of each student’s final grade, the participation rate was high for students in both sections of ANP1107 for both newsletter topics (Table 4). Out of a total of 544 students in 2019 and 648 students in 2021, 95-98% participated in newsletter creation, either as an author or an editor, and 92-96% completed the peer review portion of the assignment. The quality of the work was also good, with average scores (out of 4) for each newsletter ranging between 3.51 and 3.60 and, in part 2, very close to perfect for thoughtful completion of the peer-evaluation rubric (Table 5).

The justification comments provided by students indicated that many of them put considerable thought into the scores that they assigned to newsletters created by their peers. For example, a score of 2 out of 3 for educational value of a newsletter was justified with the explanation: “the information was valuable and educational, however, some sentences lacked clarity and would be difficult to understand for the selected audience (general public).” And a perfect score of 3 for accuracy for another newsletter was supported by: “the information was very accurate in describing what a paleo diet entails and how it can affect one’s health. Looking at the references you can see that the information was pulled from peer reviewed and other reputable sources (Stats Canada).” Finally, a perfect score of 3 for the ability to grab and maintain interest for a peer’s newsletter on intermittent fasting was justified by: “the initial appearance of the newsletter is visually appealing. The information flows well, making it easy to stay on track and follow the flow of the newsletter keeping the reader intrigued. The facts and points are clear cut.”

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The response rate for the paper-based survey conducted in 2019 was 81.8% (both classes combined). Feedback revealed that the majority of students attributed significant learning value to their participation in the gut biome newsletter assignment. Between 68 and 78% of respondents agreed or strongly agreed that the assignment gave them an opportunity to conduct self-directed learning that improved their knowledge and understanding of a topic that was a natural extension of course content and almost 60% acknowledged that the nature of the assignment provided them with important practice in written communication (Figure 1A). The majority of students also found the instructions to be clearly worded (75%) and enjoyed participating in both newsletter creation (53%) and the review of a newsletter created by their peers (57%; Figure 1B).

Table 4. Participation in Newsletter Creation and Peer Evaluation

<table>
<thead>
<tr>
<th>Year</th>
<th>ANP1107A</th>
<th>ANP1107B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newsletter Creation</td>
<td>Peer Review</td>
</tr>
<tr>
<td>2019</td>
<td>283 (97.3%)</td>
<td>273 (93.8%)</td>
</tr>
<tr>
<td>2021</td>
<td>363 (98.1%)</td>
<td>349 (94.3%)</td>
</tr>
</tbody>
</table>

Table 5. Average Scores ± SD for Newsletters (out of 4) and Peer Reviews (out of 1).

<table>
<thead>
<tr>
<th>Year</th>
<th>ANP1107A</th>
<th>ANP1107B</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Newsletter</td>
<td>Review</td>
</tr>
<tr>
<td>2019</td>
<td>3.51 ± 0.16</td>
<td>1.00 ± 0.00</td>
</tr>
<tr>
<td>2021</td>
<td>3.60 ± 0.14</td>
<td>0.99 ± 0.04</td>
</tr>
</tbody>
</table>

Figure 1.
A. Survey Feedback from ANP1107 Students regarding Learning Value of Gut Microbiome Newsletter Assignment (n=445).
B. Survey Feedback from ANP1107 Students Pertaining to Level of Satisfaction with Aspects of Gut Microbiome Newsletter Assignment (n=445).
Not all students welcomed the group work. 42% of respondents indicated that they would have preferred to work individually on the project (Figure 1B) and a comment in reply to the open-ended question regarding ways to improve the assignment was a request to allow students to self-sort themselves into groups rather than being randomly assigned. Key words that frequently appeared in student responses to the question “what I liked best about this assignment” included: creativity, interesting, effective, artistic, in-depth learning, and self-directed learning. While editors also mentioned that they welcomed the chance to be creative, they did find the editorial tasks labor-intensive and did not enjoy having to set deadlines and chase after group members who did not respect them.

In 2021, the response rate for the online survey administered to ANP1107A students was 37.3% (138 respondents in a class of 370 students). Between 76 and 86% of students found the fad diet assignment to have learning value and 76% agreed or strongly agreed that it provided opportunities for practicing their writing skills. 96% of respondents found the instructions to be clearly worded.

66% of respondents agreed or strongly agreed that the creation of a newsletter pertaining to a particular fad diet provided a welcome opportunity to interact virtually with their peers during newsletter creation and 78% found it interesting to peer review a newsletter about a fad diet that was different from the fad diet explored by their group. Creativity and the opportunity to do something different were common themes in student responses to the open-ended question of what they liked about the assignment, but several also identified the opportunity to work with other students while studying off-campus as a bonus. Two examples of such comments are: “[I liked] interacting with others in the class when that’s not so easily done now”, and “It was a nice way to meet new people in class virtually!” Of the 32 survey respondents who were editors, most of them indicated that the opportunity to create a final product based on submissions from their peers was an enjoyable experience and only three mentioned having issues with one or more of the group members not submitting their articles on time. Representative comments from editors include: “Peers were all cooperative and nice to work with in my group and met deadlines which made my job simple” and “I personally love proofreading assignments and being creative, so I thought that this assignment was amazing.”

**Discussion**

The majority of anatomy and physiology students surveyed in this study welcomed the opportunity to work together in small groups to create informative, health-related newsletters about the gut microbiome or an assigned fad diet. An important first consideration for this project was the mechanism of group creation. When dealing with large classes where the instructor does not know each student individually, groups can be created either by random assignment or by self-selection. Each method has its advantages and disadvantages. Self-selection may foster the creation of groups whose members are already acquainted with one another and so feel comfortable within the group setting, communicate well amongst themselves right from the beginning, and are able to complete projects with few within-group conflicts (Chapman et al. 2006). At the same time, self-selection may present an uncomfortable hurdle for some first-year students in large classes who have not yet established themselves within a network of peers and, therefore, feel sidelined and excluded by the self-selection process (Bacon et al. 2001).

On the other hand, random assignment can be done efficiently and easily using an LMS, has the potential to maximize group heterogeneity, is perceived as being fair to all participants, and is reflection of what students will often encounter once out in the workplace (Bacon et al. 2001; Blowers 2003; Burke 2011). While random assignment does risk creating some groups that simply do not work well together, it minimizes chances that groups will be formed that consist of a core subset of friends working together at the exclusion of one or two members of that same group who are not part of that social network – a risk when groups are formed by self-selection (Bacon et al. 2001). Given the large sizes of our classes and, most recently, the inability of students to meet in person and form friendships, we used random assignment to groups for all newsletter assignments. However, students within each group did have complete independence in determining who their editor would be and in identifying specific subtopics that each member would address.

Group assignments must be developed carefully so that communication within each group is facilitated and the instructions provided to students are clear and complete, allowing all members to have a thorough understanding of their roles and responsibilities (Burke 2011; Chiriac 2014). We provided private discussion folders for each group, so that the members could meet online and plan. Students were also free, once connections had been established within the discussion folders, to move to alternate social platforms, as long as all members were informed and in agreement to use that particular forum.

Feedback received in 2019 pointed to the importance of facilitating the role of the editor by having the instructor be the person to set all dates and deadlines, not just the date for submission of the final product. This included the date by which all group members should check in to establish their presence and meet the other group members and the date by which group members had to submit their articles to the editor. All students were advised that it was not the editor’s responsibility to chase after group members who were not staying on task; if their submission was not received on time, it would simply not be included in the final product. This revised approach was adopted in 2021 in order to minimize stress to those students who embraced editorial responsibilities and to reassure the remaining group members that the assessment of their efforts would not be jeopardized by a noncompliant student (Chiriac 2014).
In addition to facilitating in-depth learning and critical thinking, the social aspects of group work must be recognized, especially during a pandemic when students are studying in isolation. Groups allow students to develop a sense of belonging and to gain deeper insight, not only into how to be accountable while working cooperatively with other members of the team, but also into how their actions are perceived by those same team members (Burke 2011; Chiriac 2014; Falls et al. 2014). In our study, two-thirds of the 2021 survey respondents agreed that the assignment provided a welcome opportunity for interaction with their peers, an additional benefit over and above the self-directed learning that was accomplished during research for each newsletter article.

The act of being a peer assessor and providing an evaluation is an important formative assessment tool that encourages self-reflection as students compare their own work with that completed by their peers and problem solve during the provision of constructive feedback directed toward assignment improvement (Cho and MacArthur 2011; Lu and Law 2012). It is important to provide peer assessors with a scoring rubric so that students have guidance as to what parameters (optimally 3-6) should be considered while completing their evaluation (Adachi et al. 2018; Wolf and Stevens 2007). The rubric used in this study (Table 2) asked students not only to score the newsletters with regard to four criteria: accuracy, educational value, ability to engage the reader, and overall impression, but also to provide written justification of their scores, to identify strong points, and to make constructive suggestions for newsletter improvement. This is in agreement with the study of Lu and Law (2012) who showed that greater educational value is associated with the written aspect of peer evaluation – the provision of thoughtful and constructive comments – compared to the simple act of assessing a particular project and assigning numeric scores with no written justification of the score given or provision of suggestions for improvement.

There was an important limitation to this project, due primarily to time constraints imposed by the different steps in assignment completion. Students had to learn some course content first, so that they would have a knowledge foundation for newsletter research and writing (and for both projects this was course content learned 4-5 weeks into the course). They then had to be given at least one month to create their newsletter articles (authors) and incorporate the submissions into a polished final product (editors). Another 2 weeks were required for the instructors to prepare the newsletters for peer review and allow for the assessments to be completed, compiled and submitted and a further 1-2 weeks were needed for instructors to grade and provide individualized feedback for each newsletter and peer review. This meant that by the time all aspects of the newsletter project had been completed, the course was close to finishing and students were focussing on preparing for final exams. Hence, there was really no time left to share all of the newsletters with the class as a whole so that they could benefit from seeing more than just two newsletters: the newsletter they had created as a group plus the newsletter that their group had peer evaluated.

In summary, the creation of newsletters targeting a current health-related topic provides students with important opportunities to practice soft skills such as oral and written communication as well as working cooperatively as part of a group. These are skills that are valued by potential employers and will serve graduates well once they are in the workplace. Furthermore, students embraced these assignments, welcomed the opportunity to do self-directed learning and to be creative, and agreed that these assignments were a natural extension of content learned in their A&P course.

About the Authors

Jacqueline Carnegie, PhD, MEd, is an Associate Professor in the Department of Cellular and Molecular Medicine at the University of Ottawa. She teaches anatomy, physiology and pathophysiology to undergraduate students in the Faculties of Medicine, Health Sciences and Science. Her research focuses on developing learning and self-testing tools for these student populations.

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Literature Cited


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