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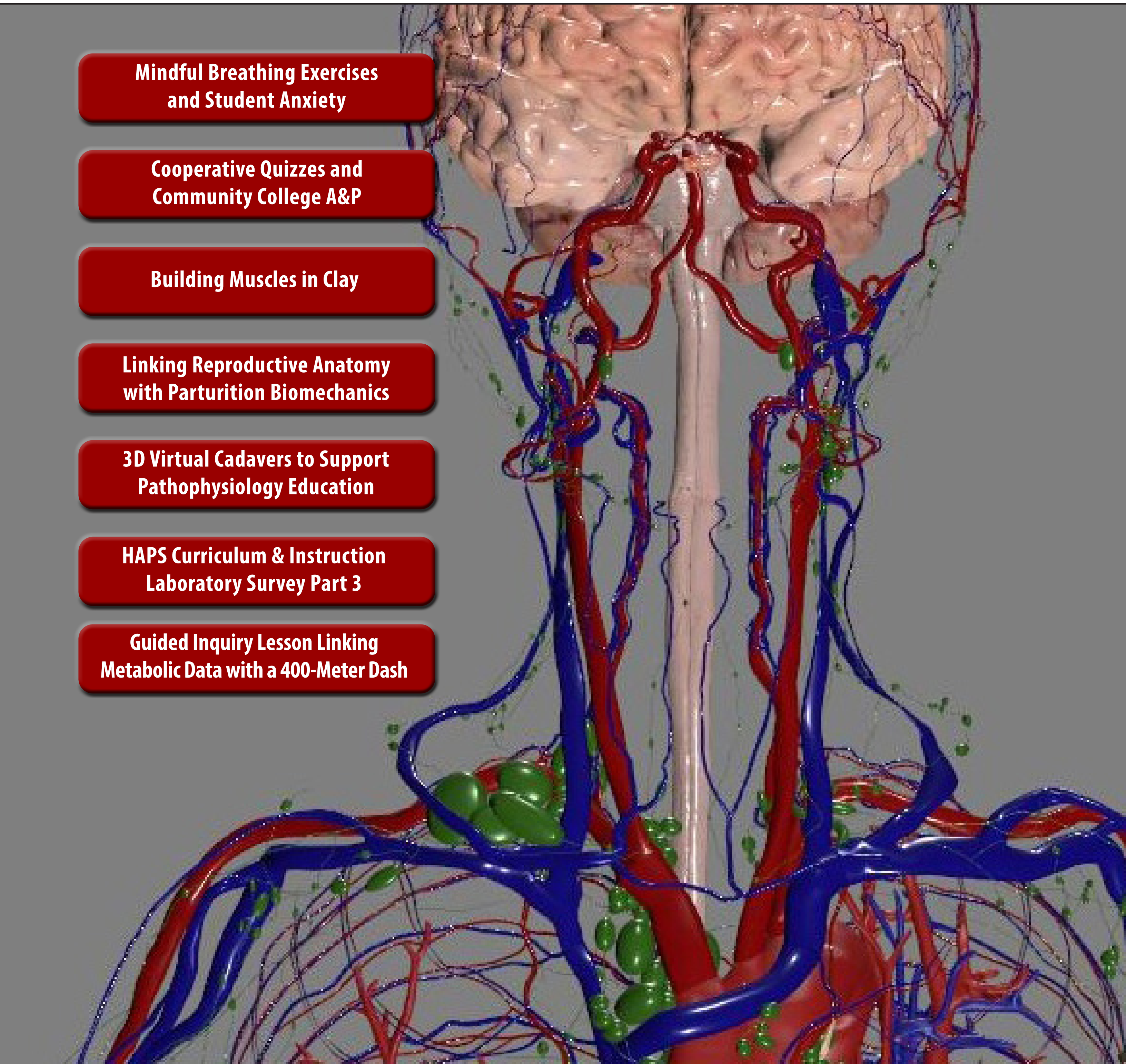

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EDUCATIONAL RESEARCH

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Do Mindful Breathing Exercises in the Classroom have a Positive Impact on Student Anxiety and Testing Experience?

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Abstract

College students report stress and anxiety when taking science courses, such as anatomy & physiology. Mindful breathing is a technique that can be used in the classroom before taking exams. To determine the impact of mindful breathing exercises on the student experience, students were randomly assigned to either course sections that included mindfulness breathing or those that did not. Both groups completed the modified twenty-question Anxiety State Self-Evaluation Questionnaire before each exam. Students in the intervention group were asked to participate in a 5-minute guided breathing exercise after completing the questionnaire, but before taking each exam. One hundred and six students (86.2%) took all four exams in the intervention group and 101 students (91.8%) in the control group. Students in the intervention group reported higher mean scores for almost all positive emotions before all four exams. The mean scores for statements describing negative emotions were generally higher for the control group than the intervention group. The guided mindful breathing intervention had no positive impact on exam performance in this study. However, the results of our study using guided mindful breathing exercises prior to taking an exam demonstrated that there was a beneficial effect on students' emotional state. Future research should explore other strategies designed to decrease test-related stress and anxiety to evaluate any potential influence on academic performance. https://doi.org/10.21692/haps.2025.001

Key words: test anxiety, mindful breathing exercises, negative emotions, positive emotions

Introduction

Stress is generally defined as the body's ability to adapt to its surroundings or situations in which it is submersed (Lu et al., 2021). This adaptation process can be defined more narrowly as a direct challenge to the body's homeostasis due to local or systemic stressors (Lu et al., 2021). A typical stress response is anxiety (Figure 1).

Like fear or nervousness, anxiety is an emotion with a prevalence of 33.3% worldwide (Gautam et al., 2022). Biological, psychological, and social causes have been attributed to the development of anxiety (Gautam et al., 2022). A meta-analysis by Wunsch and colleagues (2021) identified that the relationship between stress and academic

Figure 1. *Illustration of stress and anxiety (created by Valerie Weiss).*

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performance (AP) remains to be determined. One could hypothesize that mild levels of stress and anxiety could benefit AP positively, while higher levels of stress would ultimately have the opposite effect.

Over the last couple of years, college students have reported a significant increase in AP-related stress and anxiety. Ramon-Arbues et al. (2020) reported a moderate prevalence of anxiety (23.6%) and stress (34.5%) among college students in 2020. The American College Health Association-National College Health Assessment III survey results for 2023-2024 indicated that 33.7% of male students and 51.5% of female students reported stress as an impediment to their AP during the past 12 months. The proportion was slightly lower for anxiety at 30.4% for male students and 49.3% for female students (American College Health Association, 2024).

Assessments of students' learning, particularly summative assessments such as exams, are considered among the most stress-provoking events for college students. Not surprisingly, test anxiety is a major concern among college students, and the prevalence has risen sharply since the COVID-19 pandemic. A little more than half (56%) of college students in the United States are likely to experience test anxiety at some point (Li et al., 2022; Liyanage et al., 2021). A negative correlation between test anxiety and a student's academic achievement exists and can subsequently lead to students withdrawing from courses or dropping out of college altogether (Akhdan & Aminatun, 2022; Bäulke et al., 2022).

Stress and test anxiety among college students are not new phenomena, and efforts have been made to help college students cope with stress and reduce anxiety (Bamber & Schneider, 2016, 2022). Examples of some beneficial approaches are guided imagery, journaling, exercise, and music therapy. Meditation and other mindfulness practices have been introduced more recently as they could provide students with effective coping mechanisms in real-time to deal with stress and anxiety (Bamber & Schneider, 2016; Leland, 2015; Ramón-Arbués et al., 2020; Rosenzweig et al., 2010).

However, whether mindfulness practices can improve students' AP remains elusive (Bóo et al., 2020). Vorontsova-Wenger et al. (2021) reported a positive correlation between mindfulness practice and AP. However, a systematic review by Dawson and colleagues (2020) did not find conclusive evidence of a positive effect on AP.

Lower-level science courses at colleges and universities are often more stressful and anxiety-inducing than non-science courses. For one, students are notoriously underprepared for the rigor required to be successful (Thiry, 2019). A second reason is that many of the courses are considered "gateway courses" for the students' chosen majors or future careers. Failing to pass a course, or even not earning a high enough grade, may hinder students from obtaining a degree in their major and reduce their chances of being admitted into graduate programs. For example, anatomy and physiology (A&P) courses are often prerequisites for certain undergraduate degrees (such as Nursing and Exercise Science) and for admission to graduate programs (such as the Doctor of Physical Therapy, Occupational Therapy, and Physician Assistant). Due to the popularity of these programs, students know that passing A&P courses is most likely not enough for a successful application. Unfortunately, students in college science courses often earn final grades of D or F, or even withdraw from the course partway through (Cohen & Kelly, 2018). Students are typically aware of the high-stakes nature of science courses, which can contribute to additional stress and anxiety.

With more than 30 years of combined teaching experience in basic and advanced A&P and related pre-health professions courses, the authors of this study have encountered many students with self-proclaimed "test anxiety" or "fear due to the inherent consequences of failing a course." These students attribute their inability to earn better grades to anxiety and fear. Therefore, this study aimed to determine if guided mindful breathing exercises (Figure 2) in the classroom before students wrote exams positively impacted their test anxiety and exam scores.

Figure 2. *Mindful breathing (illustration created by Valerie Weiss).*

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Methods

Ethical research statement

The Institutional Review Board of Florida Gulf Coast University (FGCU) approved the research protocol and its amendment prior to data collection (FGCU IRB 2018-57). All participants provided written consent before participating in this study. All faculty involved in the study were trained in ethical data collection through the Collaborative Institutional Training Initiative, and data collection followed all laws relevant to the survey of university student populations. Participation in the study was voluntary, and participants did not receive compensation or any kind of benefit, such as extra credit.

Data collection

Students from the Anatomy & Physiology with lab I (A&P I) section were randomly assigned to either the intervention group or control group. Typically, students take the A&P I course in their first or second semester in college. Both groups used the same course materials, followed the same syllabus, and were assessed with same written exams. Students in both groups were asked to complete a twenty-question Anxiety State Self-Evaluation Questionnaire before each exam (Table 1). The questionnaire was adapted from the Competitive State Anxiety Inventory-2 Illinois Self-Evaluation Questionnaire (Craft et al., 2003). Students were asked to select one of four answer options in response to each of the statements on the questionnaire.

Directions: *A number of statements that can be used to describe feelings related to taking an exam are given below. Read each statement and then circle the appropriate number to the right of the statement to indicate how you feel right now. There are no right or wrong answers. Do not spend too much time on any one statement, but choose the answer that describes your feelings right now.*

		Not at all	Somewhat	Moderately so	Very much so
1	I feel nervous	1	2	3	4
2	I feel at ease now	1	2	3	4
3	I have self-doubts	1	2	3	4
4	I feel jittery	1	2	3	4
5	I feel comfortable	1	2	3	4
6	I am concerned that I may not do well in this exam	1	2	3	4
7	I feel exhausted	1	2	3	4
8	I feel self-confident	1	2	3	4
9	I am concerned about failing	1	2	3	4
10	I feel tense in my stomach	1	2	3	4
11	I feel secure	1	2	3	4
12	I am concerned about choking on exams	1	2	3	4
13	My body feels relaxed	1	2	3	4
14	I am confident I can succeed	1	2	3	4
15	I am confident about performing well	1	2	3	4
16	I feel mentally relaxed	1	2	3	4
17	My hands are clammy	1	2	3	4
18	I am concerned about passing this class	1	2	3	4
19	My body feels tight	1	2	3	4
20	I am confident of coming through under pressure	1	2	3	4

Table 1. *Anxiety State Self-Evaluation Questionnaire.*

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Students in the intervention group were asked to participate in a 5-minute guided breathing exercise after completing the Anxiety State Self-Evaluation Questionnaire but before taking each exam. They were encouraged to actively engage in the exercise by sitting up straight, closing their eyes, and following the instructions of the recorded breathing exercise. We used a recorded Guided Meditation 5-minute mindfulness of breath mp3 file before each exam. Using this recording across sections allowed for a consistent breathing exercise experience for all students in the intervention group. Once the breathing exercise had finished, students were allowed to start taking the exam. Students in the control group took the exams without engaging in pre-test breathing exercises. Both groups had the same amount of time for the exams.

Students in both groups took four exams during the semester. Exam 1 was administered during week 4, Exam 2 during week 9, Exam 3 during week 12, and Exam 4 during the final week of the term (week 15). Exams 1-3 covered between three and five chapters in the textbook; Exam 4 was cumulative and covered all 14 chapters studied during the term.

Data analyses

Statistical analyses were performed using the IBM SPSS, version 29.0, statistical software package. All data were analyzed using a confidence interval of 95% and a significance level of 0.05. The answers on the Anxiety State Self-Evaluation Questionnaire were graded on a 1-4 scale and, thus, considered ordinal data. Since the survey produced ordinal data, the nonparametric Mann-Whitney U test was used to determine the difference between the intervention and the control group.

Results

Study population

Overall, 238 students were enrolled in eight different A&P I courses, all with a lab. The classes were randomly assigned to either the intervention or control group. Five students never showed up to class, leaving 233 participants for our study, of which 123 were in the intervention group and 110 in the control group. Not all students remained in class until the end of the semester and some students missed an exam for a variety of reasons. A total of 106 students (86.2%) in the intervention group and 101 students (91.8%) in the control group took all four exams. Students who were registered for accommodations under the Americans with Disabilities Act (ADA) took exams at the offices of Adaptive Services and students who made up missed exams were excluded from engaging in pre-exam breathing exercises for logistical reasons. They were automatically assigned to the control group.

Impact on students' emotional state

The twenty statements on the questionnaire can be subdivided into:

1. statements that describe negative emotions (e.g., *I feel exhausted*)
2. statements that describe positive emotions (e.g., *I feel self-confident*)
3. statements that describe emotions shaped or influenced by past performance or current grades (e.g., *I'm concerned about choking on exams*)

The mean scores for statements describing negative emotions (1, 3, 4, 6, 7, 10, 17, 19) were generally higher for the control group than the intervention group (Table 2). However, the differences were significant only for statement 1 for Exam 3 ($p = 0.001$), statements 3, 4, and 10 for Exam 4 ($p = 0.045$, 0.001, and 0.018, respectively), and statement 19 for Exam 3 ($p = 0.015$). Statement 7 ('*I feel exhausted*') was the only one of this group with significant differences between the intervention group and control group for more than one exam (Exam 1 $p = 0.002$; Exam 3 $p = 0.04$; and Exam 4 $p = 0.05$). Statements 10, 17, and 19 related more to physical responses to anxiety and had rather low average scores with no significant difference between both groups, but for two exams.

Students in the intervention group reported higher mean scores for almost all positive emotions (2, 5, 8, 11, 13, 14, 16, 20) for all four exams. However, the differences between the mean scores were only significant for 11 of 32 exams overall. The differences were significant for statement 2 in Exams 2 and 4 ($p = 0.001$ and 0.03), for statement 5 in Exams 3 and 4 ($p = 0.04$ and 0.05), for statement 8 in Exam 4 ($p = 0.016$), for statement 16 in Exams 1 and 2 ($p = 0.02$ and 0.02). Statement 13 ('*My body feels relaxed*') was the only statement with a significant difference between intervention and control groups for all four exams ($p = 0.002$, 0.001, 0.007, and 0.004, respectively). None of the mean scores for statements describing emotions shaped or influenced by past performance or current grades (9, 12, 15, 18) was significant (Table 2).

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		Exam 1			Exam 2			Exam 3			Exam 4		
		IC	CG	*p*	IC	CG	*p*	IC	CG	*p*	IC	CG	*p*
1	I feel nervous	2.7	2.9	0.22	3.0	3.1	0.53	2.5	3.0	**0.001***	2.9	3.0	0.07
2	I feel at ease now	2.3	2.0	0.15	2.0	1.7	**0.001***	2.1	2.0	0.20	2.1	1.8	**0.030***
3	I have self-doubts	2.5	2.5	0.83	2.7	2.8	0.44	2.4	2.7	0.12	2.5	2.8	**0.045***
4	I feel jittery	2.2	2.3	0.13	2.4	2.6	0.19	2.2	2.5	0.078	2.1	2.6	**0.001***
5	I feel comfortable	2.5	2.2	0.10	2.2	2.1	0.49	2.5	2.2	**0.04***	2.3	1.9	**0.05***
6	I am concerned that I may not do well in this exam	2.5	2.6	0.79	2.8	2.8	0.77	2.6	2.7	0.75	2.6	2.7	0.45
7	I feel exhausted	2.0	2.5	**0.002***	2.3	2.6	0.07	2.0	2.4	**0.04***	2.1	2.5	**0.05***
8	I feel self-confident	2.6	2.3	0.53	2.3	2.3	0.97	2.5	2.4	0.63	2.5	2.2	**0.016***
9	I am concerned about failing	2.6	2.5	1.00	2.7	2.6	0.68	2.3	2.5	0.62	2.4	2.6	0.19
10	I feel tense in my stomach	1.7	1.9	0.06	2.0	2.0	0.99	1.8	2.0	0.18	1.9	2.3	**0.018***
11	I feel secure	2.3	2.1	0.44	2.0	2.1	0.95	2.4	2.2	0.15	2.3	2.0	0.23
12	I am concerned about choking on exams	2.3	2.4	0.79	2.4	2.5	0.708	2.2	2.4	0.502	2.5	2.6	0.81
13	My body feels relaxed	2.4	1.9	**0.002***	2.1	1.7	**0.001***	2.2	1.9	**0.007***	2.2	1.8	**0.004***
14	I am confident I can succeed	2.7	2.5	0.95	2.5	2.4	0.49	2.8	2.6	0.86	2.6	2.4	0.286
15	I am confident about performing well	2.6	2.3	0.79	2.3	2.2	0.73	2.5	2.5	0.27	2.5	2.3	0.083
16	I feel mentally relaxed	2.5	1.9	**0.02***	2.1	1.9	**0.02***	2.2	2.0	0.07	2.1	1.8	0.07
17	My hands are clammy	1.8	1.8	0.70	2.0	1.9	0.56	1.7	1.9	0.12	2.0	2.0	0.29
18	I am concerned about passing this class	2.7	2.7	0.98	2.7	2.7	0.75	2.5	2.6	0.73	2.3	2.6	0.06
19	My body feels tight	1.7	1.9	0.08	2.0	2.2	0.57	1.8	2.1	**0.015***	2.0	2.3	0.07
20	I am confident of coming through under pressure	2.5	2.4	0.88	2.3	2.2	0.29	2.4	2.4	0.66	2.5	2.3	0.07

*denotes significance

***Table 2.** Mean scores for intervention group (IG) and control group (CG) and p-values for all statements of the Anxiety State Self-Evaluation Questionnaire for exams 1-4.*

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Performance on exams

When comparing the scores for Exams 1-4, while there appeared to be a trend for students in the control group to have higher mean scores, a significantly higher mean score for the control group ($p = 0.038$) was found only for Exam 2 (Table 3).

When comparing the scores related to emotional statements (9, 12, 15, 18) that may have been influenced by past performance and the grades that students received on exams, it appeared that students earning an A or a B (A/B students) generally had lower scores than students scoring a C, D or F (C/D/F students) on all exams. However, this difference was not significant and there was also no significant difference between the intervention and control groups (Table 4).

Discussion

The purpose of this study was to determine whether guided mindful breathing exercises before written exams had a positive impact on test anxiety and exam scores. The results of our study indicate that engaging in guided mindful breathing exercises (Figure 3) prior to taking a written exam had a small positive effect on the emotional state of students. Similar findings correlating mindfulness meditation to decreased self-perceived anxiety and stress have been reported previously (Crowley et al., 2022; Shapiro et al., 1998). Compared with students in our control group, students in the intervention group tended to have lower mean scores for statements that describe negative emotions and higher mean scores for statements that describe positive emotions. However, of the 64 statements analyzed (16 statements on 4 exams each), the differences for only 19 statements were significant.

	Intervention Group	Control Group	*p*-value
Exam 1	84.1 ± 11.3	85.4 ± 13.7	0.103
Exam 2	77.3 ± 12.3	80.3 ± 14.0	**0.038***
Exam 3	77.3 ± 15.7	79.6 ± 15.6	0.182
Exam 4	75.1 ± 13.2	75.7 ± 15.2	0.291

*denotes significance

Table 3. *Mean scores ± standard deviation for the intervention and control groups for Exams 1-4.*

		Exam 1		Exam 2		Exam 3		Exam 4	
		IG	CG	IG	CG	IG	CG	IG	CG
#9	A/B students	2.6	2.5	2.7	2.6	2.3	2.5	2.4	2.6
	C/D/F students	3.1	2.6	3.4	2.5	3.8	2.7	3.3	3.0
#12	A/B students	2.3	2.4	2.4	2.5	2.2	2.4	2.5	2.6
	C/D/F students	2.3	2.1	2.3	2.6	3.0	2.8	2.6	2.7
#15	A/B students	2.6	2.3	2.3	2.2	2.5	2.5	2.5	2.3
	C/D/F students	2.3	2.1	1.9	2.3	1.6	2.4	1.8	2.2
#18	A/B students	2.7	2.7	2.7	2.7	2.5	2.6	2.3	2.6
	C/D/F students	3.4	3.1	3.6	3.1	3.8	2.9	3.1	3.1

Table 4. *Mean scores for statements that describe emotions shaped or influenced by past performance or current grades for students who earned a grade of A or B on all exams (A/B students) and students who earned a grade of C, D, or F on all exams (C/D/F students) for the intervention (IG) and control groups (CG).*

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Figure 3. *Positive responses to mindful breathing (illustration created by Valerie Weiss).*

There was no positive impact of the guided mindful breathing intervention on the performance of students in exams in our study. This finding was surprising and in contrast with the findings of Bennett & Dorjee (2016) and Lampe et al.(2021), who reported improved test results following mindfulness stress reduction. The data do not clearly indicate why the control group had better mean scores. It could be due to the unbalanced number of students in each group. The relatively small sample size could have resulted in an imbalance in academic performance between the groups. Additionally, different instructors were leading the guided mindful breathing exercises and might not have taken the exercise seriously. Lastly, it could have been possible that better students ended up in a particular course section through self-registration.

Upon further analysis of the impact of guided mindful breathing exercises, meditation was found to have a greater influence on positive rather than negative emotions. Only one statement related to negative emotion (#7, *'I feel exhausted'*) demonstrated a significant difference between the intervention and control groups across multiple exams. On the other hand, three statements describing positive emotions (#2, "*I feel at ease no*"; #5, *"I feel comfortable"*; #16, *"I feel mentally relaxed"*) had significant differences between the intervention group and control group for two exams, and the differences for statement #13, *"My body feels relaxed"*, were significant for all four exams.

When comparing the scores for the different exams, Exam 2 was notably the only exam with no substantial difference for any of the negative emotions between groups. Additionally, the mean scores for groups were higher than for the other three exams. While there was a significant difference in mean scores for three positive emotions for Exam 2, the mean scores for all positive emotions were relatively lower than those for the other exams. Exam 2 can be the most telling exam of the semester for most students. Students who perform well on Exam 1 are aiming to sustain that level whereas students who perform poorly on Exam 1 are anxious to improve their grade.

By the time students take the final exam of the semester (Exam 4), most of them already perceive what their final grade in the course will be based on their overall average shown in Canvas. Unless students underperform or overperform, their overall score will not change much at this point in the semester. For example, a student having an overall score of 72% before Exam 4 would have to earn a score of less than 65% on Exam 4 to lower their overall score below 70% (the threshold score for a final grade of 'C' in the course). Therefore, it is unsurprising that 8 of 16 statements showed significant differences between the intervention and control groups.

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It seems logical to assume that past life experiences influence current experiences and thus can affect both anxiety and stress levels (Juruena et al., 2020). When assessing questions such as "*I am afraid of failing*" or "*I am concerned about choking*," one can assume that these reflect domains of previous experiences. The results of this study demonstrate a non-significant but interesting relationship. Low-performing students (C/D/F students) were likely more worried about failing the class (Statements 9 and 18) and, therefore, less confident about performing well (Statement 15) before taking the first exam than high performing students (A/B students). Surprisingly, the gap between low and high-performing students for these items was larger for IG than CG students, and low-performing IG students tended to report higher scores for statements 9 and 18 and lower scores for statement 15. These findings correlate with the hypothesis that a mindfulness practice appears to have a positive effect on students' emotional state.

There are several limitations to this study. Mindfulness breathing practice was only used four times during the semester. As a result, that may have only partially benefitted the students' overall anxiety and stress levels and future studies should evaluate the effect of weekly mindfulness breathing. Using an outcome measure that has yet to be evaluated for its validity and reliability is also a limitation. One could also argue that some of the statements that we related to positive or negative emotions could be considered to be dependent on or influenced by students' prior performance in this or other courses. For example, we considered statement #8, "*I am self-confident*," to describe a positive emotion. However, students who came into the course with bad experiences in science classes in high school or at our university may have been influenced by these prior experiences when selecting an answer option. We did not evaluate the students' experiences of the mindfulness breathing practice or any perceived impact this might have had for them during the semester. Future studies should evaluate this further.

Conclusions

The results of our study using prerecorded guided mindful breathing exercises prior to taking an exam demonstrated that there was an effect on students' emotional state. The effect was slightly more significant for enhancing positive emotions than for reducing negative ones. There was, however, no effect on students' overall performance in written exams. Future research should explore additional strategies, beyond mindfulness practices, that are designed to lower students' exam-taking stress and anxiety and determine how this might translate into better academic performance.

About the Authors

Rob Sillevis is an associate professor at Florida Gulf Coast University who teaches program research, movement sciences, and physical therapy courses in a Doctor of Physical Therapy program. He has had a long-standing interest in mindfulness and mediation. Valerie Weiss teaches undergraduate anatomy, and physiology at Florida Gulf Coast University. She designed the curriculum for the course in Medical Literature, Anatomy and the Arts. As a trained medical illustrator, her research interest is in using drawing to enhance her students' anatomy education. Valerie Weiss also created Figures 1, 2 and 3. At the time of this study, Peter Reuter was an assistant professor teaching undergraduate and graduate A&P courses and Florida Gulf Coast University. He was a member of the Honors College Executive Board and an Honors College Faculty Fellow. He is now retired.

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The Impact of Cooperative Quizzes on Test Anxiety and Course Completion Rates in a Community College Level 1 A&P Course

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Abstract

This study investigates the efficacy of cooperative quizzes in reducing test anxiety and improving course success rates among community college students. Test anxiety was measured using a mini-SPIN survey provided by the RECAPER project. Twenty students completed pre-semester and post-semester surveys. Statistical analyses revealed no significant difference (Student's t-test, $p>0.05$) in test anxiety levels or success rates between the two groups. These finding suggest that cooperative quizzes may not offer significant advantages in reducing test anxiety or improving course outcomes compared to traditional quiz formats. Nevertheless, students' responses indicated that cooperative quizzes had a positive impact on their learning. https://doi.org/10.21692/haps.2025.002

Key words: active learning, test anxiety, collaborative quizzes, collaborative testing

Introduction

Commonly used phrases like "the design team" or "the development team" are clear efforts to harness the power of a collaborative effort to meet goals and accomplish tasks in various industries. In contrast to most employment settings, and despite plenty of evidence and encouragement to the contrary (Bloom, 2009; Cardozo et al., 2020; Deslauriers et al., 2019; England et al., 2017; Freeman et al., 2014; Giuliodori et al., 2009; Lusk & Conklin, 2003), the focus in academic settings continues to be placed on the isolated performance of the student when it comes to their learning and assessment. This individualistic approach runs contrary to Bandura's social cognitive theory, the constructivist theory (Kay & Kibble, 2016), and a growing list of pedagogical studies and reviews that emphasize the importance of human interaction and collaboration during the learning process (DiCarlo, 2009; Giuliodori et al., 2009; Mallow, 2006). In addition, the continued emphasis placed on individual, isolated achievement in academics is a contributing factor to increased anxiety (Chapell et al., 2005; Pandey & Kapitanoff, 2011), a state that Reinhard Pekrun (2006) describes as "an achievement emotion" directly tied to a student's perceived ability to reach a specific outcome. An elevated sense of anxiety is not only potentially unhealthy (Center for Collegiate Mental Health. 2017 Annual Report, 2018), but can also have a negative effect on academic achievement (Bell et al., 2021; Cardozo et al., 2020; Downing et al., 2020;

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England et al., 2017) and may threaten student persistence in STEM courses (Downing et al., 2020; England et al., 2017; Freeman et al., 2014; Hood et al., 2021). With these challenges to student mental health, academic achievement, and persistence, can the introduction of a more collaborative approach to learning and assessment result in better outcomes?

One challenge to answering this question is that studies of the impacts of collaborative learning on test anxiety are not consistent (Bell et al., 2021; Bloom, 2009; Cardozo et al., 2020; England et al., 2017; Hood et al., 2021; Rivaz et al., 2015). Among the purported benefits of a cooperative approach to learning are reduced anxiety and improved performance on course tests (Rao et al., 2002; Rivaz et al., 2015). One tool that has been used to move learning away from an instructor-centered approach and towards a student-centered focus is the use of cooperative quizzes. Specifically, students first complete a quiz individually. Afterwards, the students are put into small groups of 2 or 3 and work together to complete the same quiz again. This cooperative testing practice turns single-stage, individual-effort assessments into a two-stage process that has both individual and collaborative parts (Bloom, 2009; Rao et al., 2002).

Due to the contrasting conclusions and the fact that most studies completed so far were carried out in a university setting, there is a need for additional investigation of the effects of evidence-based instructional practices (EBIPs), like collaborative quizzing, in the community college (Bloom, 2009; Cardozo et al., 2020; England et al., 2017; Gilley & Clarkston, 2014; Rao et al., 2002; Rivaz et al., 2015). Therefore, the aims of this study were to answer the following two questions:

Do students taking a community college entry-level anatomy and physiology (A&P) course experience reduced test-taking anxiety compared to controls when cooperative quizzes are used?

Do students taking a community college entry-level A&P course that includes cooperative quizzing experience increased course completion rates compared to controls?

Methods

This study was conducted at Delaware County Community College (DCCC) during the fall 2023 semester which began on August 28, 2023, and ended on December 15, 2023. This project was approved by the Institutional Review Board (IRB) of Delaware County Community College, and informed consent was obtained from all participants. The study involved several sections of an entry-level A&P course (BIO 150). Each section met in-person twice per week for one hour and twenty-five minutes per meeting. A *flipped classroom* delivery was used with class meetings used to address student questions related to chapter study guide questions provided at the start of the semester. Student learning in the lecture portion of the course was assessed using seven quizzes, seven tests, and a comprehensive final exam. In addition, several hours per week were available for students to meet collectively with the instructor for learning support.

During the first week of instruction, students in all sections were notified verbally and via email that they were registered in a section of BIO 150 where the instructor was conducting a research study. Time was allotted at the beginning of the course to explain and share the theoretical basis for the use of cooperative quizzes, a detailed explanation of how the quizzes would be carried out by the instructor and students, and how this EBIP will factor into the calculation of the students' grades. The goal of providing this explanation of the study was to reduce anxiety and resistance to the incorporation of this novel intervention in the course.

Informed consent, demographic, and student anxiety data were obtained via an online Qualtrics survey. The survey was provided by the Refinement and Expansion of the Community College Anatomy and Physiology Research (RECAPER) project. In addition, an eight-item, modified version of the instructional practices and social anxiety survey used by Bell et al., (2021) was included in the survey to all participants before the first course test and the same survey was delivered once more before the last unit test. A crossover design was utilized so that each student participant received the intervention for half the semester and then served as a control for the other half of the semester.

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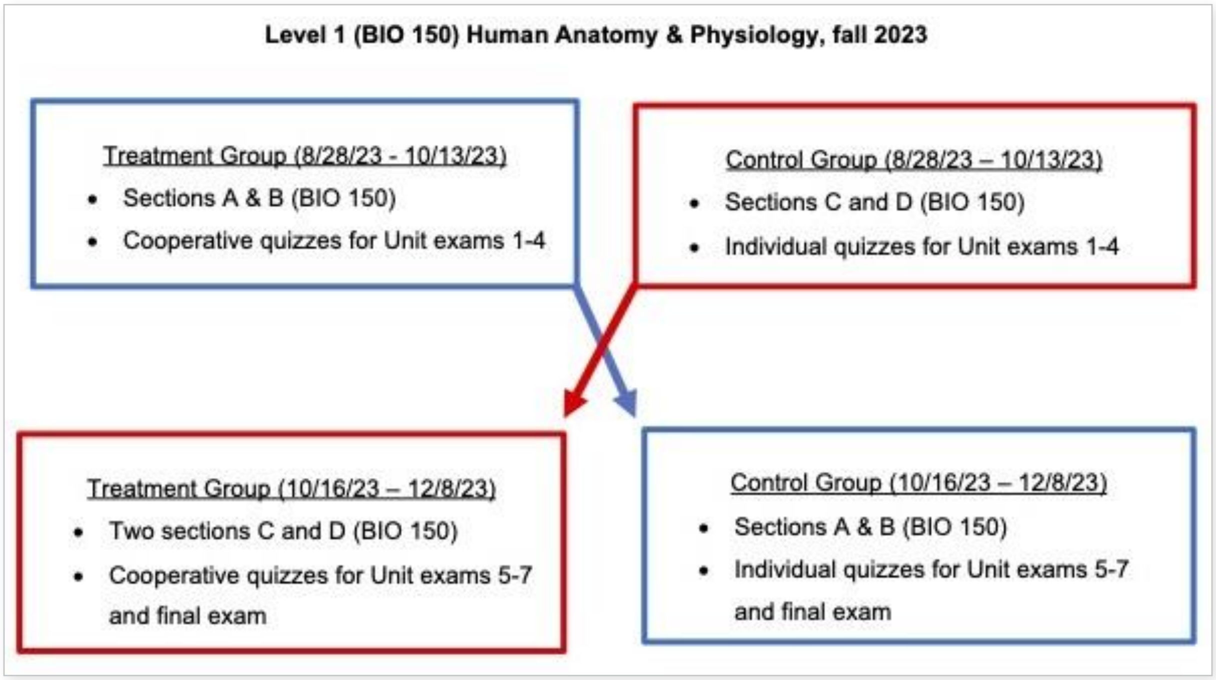

Figure 1. *Experimental Design*

In the treatment groups, students were randomly assigned to work in groups of two or three. One cooperative quiz was administered per two chapters of course material for a total of seven quizzes. The quizzes were administered during the last 45 minutes of class. During the first 25 minutes, students completed their individual attempt of the quiz. Immediately after collecting the individual-attempt quiz, students completed the collaborative quiz over the next 15 minutes of class. Similar to Rieger & Heiner (2014), the student's result on an individual attempt was worth 85% of the total points for a quiz while the group attempt made up 15% of the points for a quiz. In any case where a student's individual attempt score was greater than their group score, the individual score accounted for 100% of the quiz score (Rieger & Heiner, 2014). Based on the recommendations in the literature (Giuliodori et al., 2009), the rationale for each correct answer and timely feedback was provided as the instructor reviewed the quiz with the class during the last 5-10 minutes of the class.

During the part of the semester when two course sections were participating as the control groups, the same class structure (i.e., flipped, active learning, learning support, etc.) was used, the students completed the same unit tests and individual quizzes as the treatment group.

Results

The study involved four separate sections of BIO 150 (n = 96) with 89 students completing the semester-start survey. By the end of the semester, only 20 students who had completed the semester-start survey completed the semester-end survey. The conclusion to the two experimental questions asked were as follows.

Students' Rating of Anxiety

The mean anxiety level reported by the 20 students at semester-start was 5.8 4.0 compared to 4.9 2.9 at semester's end. A Student's paired-sample t-test revealed no significant difference in anxiety between the two time points.

Success Rate Comparison

The tests used to assess students during the study were the same as those used during the fall 2022 semester. As a result, BIO 150 success rates (i.e., earning a grade of "C" or higher) were compared between fall 2022 and fall 2023. An independent samples Student's t-test revealed no significant difference in success rates when comparing the two semesters.

The fact that 20 students completed the semester-end survey reduced the power of the study and made it necessary to focus on the qualitative implications of this investigation. The first question that was considered was: Did students do better on their cooperative quizzes than their individual quizzes?

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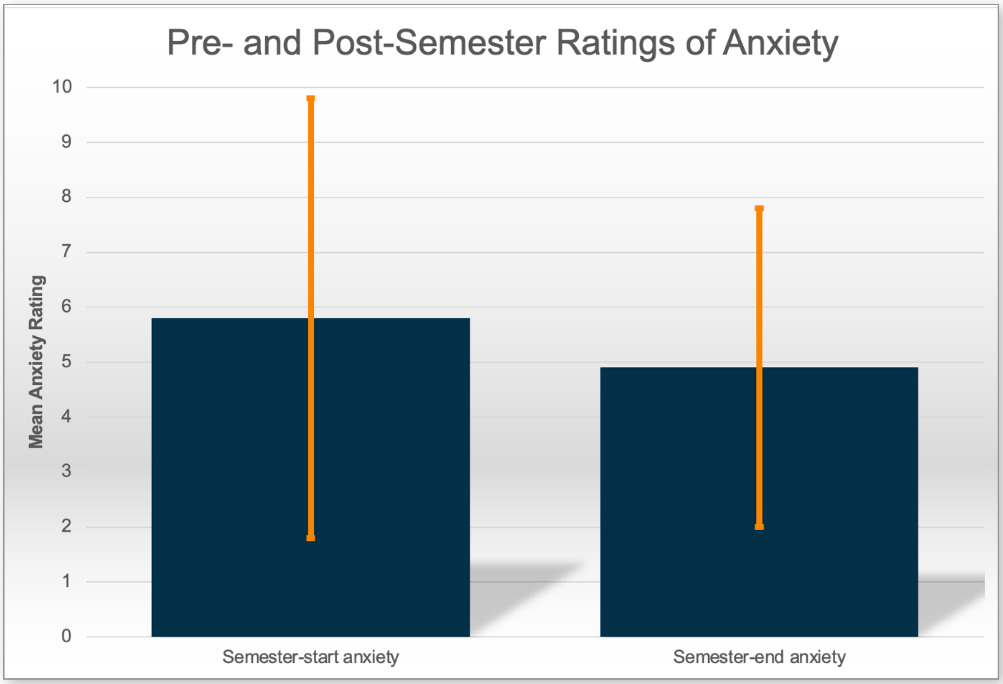

Figure 2. *Students' Pre-semester to Post-semester Anxiety Ratings (n=20)*

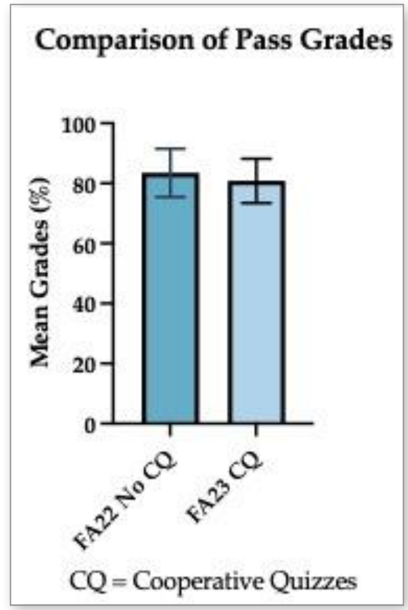

Figure 3. *Student Success Rates Fall 2022 vs. Fall 2023 (FA22 n= 24, FA23 n=38)*

Comparison of individual quiz scores to cooperative quiz scores

Seven quizzes were administered to students during the semester comprising 10% of the course grade. Each quiz was scored out of 20 points possible. Since the number of students registered in the course changed, and because students participated as part of the treatment group and control group during the semester, an unpaired Student's t-test was used to compare means. The test revealed a mean quiz score of 11.18 out of 20 (56%) for all individual quizzes taken while the mean cooperative quiz score was 15.615 out of 20 (78%), a statistically ($p < 0.05$) and practically significant difference in quiz scores.

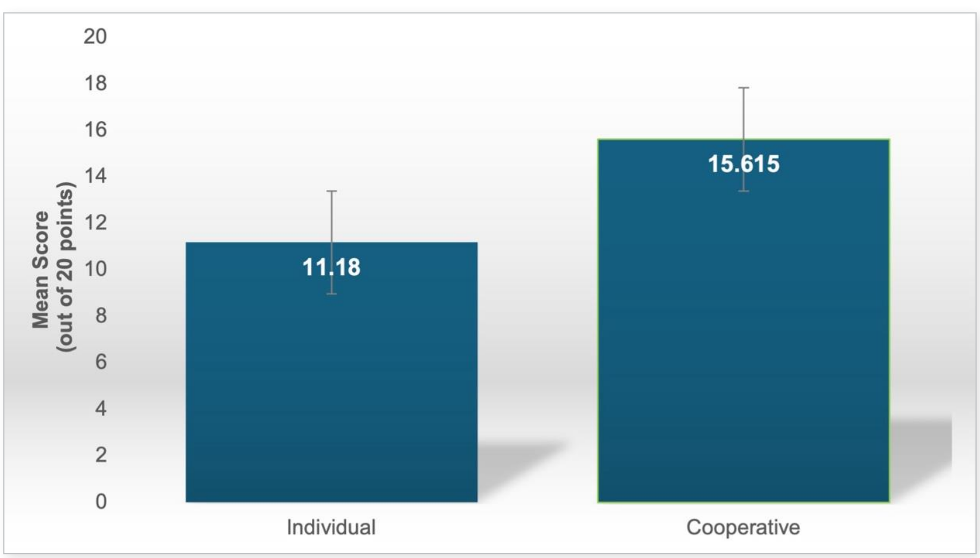

Figure 4. *Did Cooperative Quizzes Improve Students' Quiz Scores? (200 observations)*

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During cooperative quizzes, students were observed comparing ideas, reasoning with each other, debating differences in understanding, and ultimately, learning with each other. These same students would have likely sat quietly in their chairs for the whole semester without speaking more than a few course-material-related sentences to another person in the class, were it not for cooperative quizzing. This was exciting to witness and, while the benefits of these interactions cannot be quantified in this study, they can certainly be proposed. The next question considered was: Did the students perceive any benefits to their learning from cooperative quizzes and the other active learning strategies employed in the course?

One of the challenges to parsing out the benefits of cooperative quizzes in this study was the use of other active learning strategies used in the course. The additional learning tools included a flipped classroom design and several hours per week of supplemental instruction outside of the classroom. The variety of active learning strategies employed, together with the number of students who completed the end-semester survey, resulted in student comments that touched on each learning tool included in the course. Table 1 presents end-semester survey comments grouped into the six different learning tools used. It is important to note that the comments in Table 1 were offered by the 20 students who completed the semester-end survey. Through analysis of these comments, it became clear that the active learning tool commented on most frequently were the recorded lectures for each unit. Students appreciated the ability to listen to challenging material as many times as they wanted to and learn at their own pace. Students commented on several learning strategies that they said helped them navigate the demands of learning in this course. Their comments included the use of mock tests, active notetaking while listening to the recorded lectures, and seeking help via in-class and supplemental instruction sessions.

It was satisfying to note that five out of the 20 students mentioned group learning in their comments since cooperative quizzing was the focus of this research study. Students appreciated the opportunity to fill in gaps in their understanding and knowledge with a peer. The groups were randomly assigned for each quiz, which maximized the potential for exposure to the different learning strategies being used by students.

Several hours of additional learning support, referred to as "Student Support Hours" or "SSH," were scheduled each week. These were offered in addition to the active learning and student-teacher interactions of scheduled class meetings. Students appreciated being able to ask specific questions about topics of interest to them both in class and during SSH as a way of reinforcing their confidence regarding what they were supposed to know.

Active Learning Tool	# of Comments (out of 20 students)	Sample Comment
Recorded Lectures	8	"Listening to the lectures was helpful, I can rewind and pause when I need to."
Learning Strategies	5	"I would perform mock tests on myself based on the study material in order to prepare for the tests."
Cooperative Learning	5	"The activities that were very helpful for me where [sic] the group quizzes they helped fill in gaps and information."
Supplemental Instruction	3	"I can clarify my questions with SSH [Student Support Hours]."
Active Learning Classroom	3	"Participating in class was extremely helpful for me. It allowed me to work out the material as often times, I was misunderstanding without realizing I was misunderstanding."
Course Tests	1	"I think the tests helped me the most in developing effective study strategies."

Table 1. *Students' Comments About Cooperative Learning and Active Learning*

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Discussion

The purpose of this study was to investigate whether the use of collaborative quizzes in an entry-level A&P community college course would decrease student test anxiety and improve success rates. The results of this investigation may indicate that the use of cooperative quizzing as an EBIP may not reduce student anxiety. This finding would be in line with previous studies (Bell et al., 2021; England et al., 2017; Hood et al., 2020, 2021; Salloum et al., 2024) that reported either no change or an increase in student anxiety when using active learning strategies. The potential anxiogenic effects of active learning strategies like cooperative quizzing appear more often in community college students who are non-white, are from a lower socioeconomic status, and are first generation college students (Downing et al., 2020; Hood et al., 2020; Theobald et al., 2020). Figure 5 illustrates that more than half of the students who participated in this study come from ethnic backgrounds that are associated with a lower socioeconomic status (SES), with 45% reporting first generation status.

In addition, other researchers have presented results that link gender and anxiety, with females reporting higher anxiety levels than males (Mallow, 2006; Theobald et al., 2020; Udo et al., 2004). Figure 7 shows that 80% of the participants in the present study were female. Taken together, these demographic factors may help explain the lack of effect of collaborative quizzing on student anxiety and success rates.

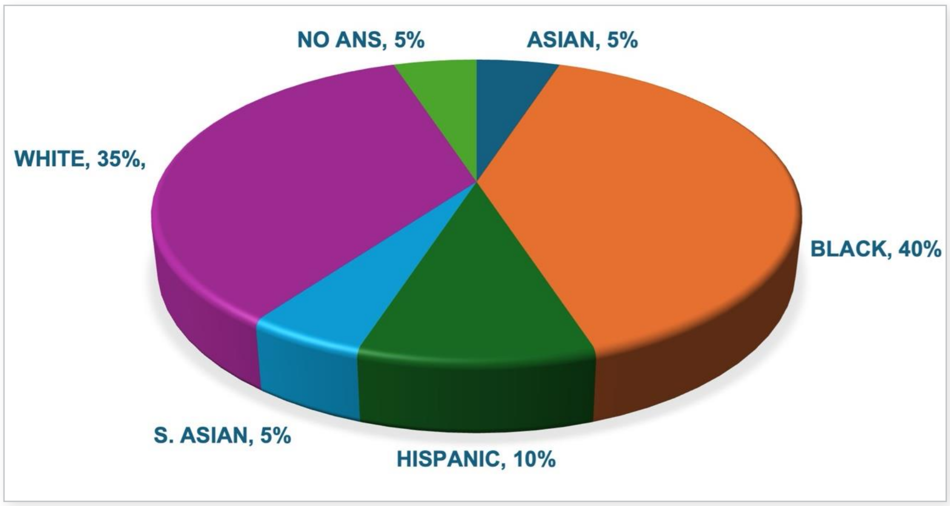

Figure 5. *Student Demographics – Ethnicity (n=20)*

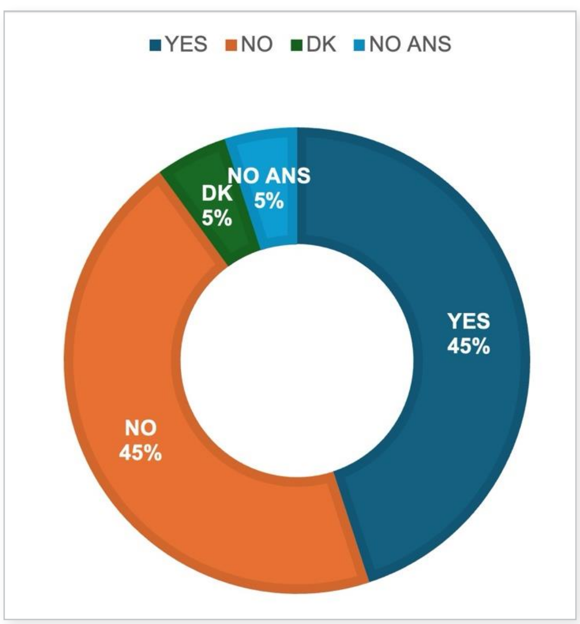

Figure 6. *Student Demographics – 1st Generation College Student (n=20) DK = Don't Know; NO ANS = Not Answered*

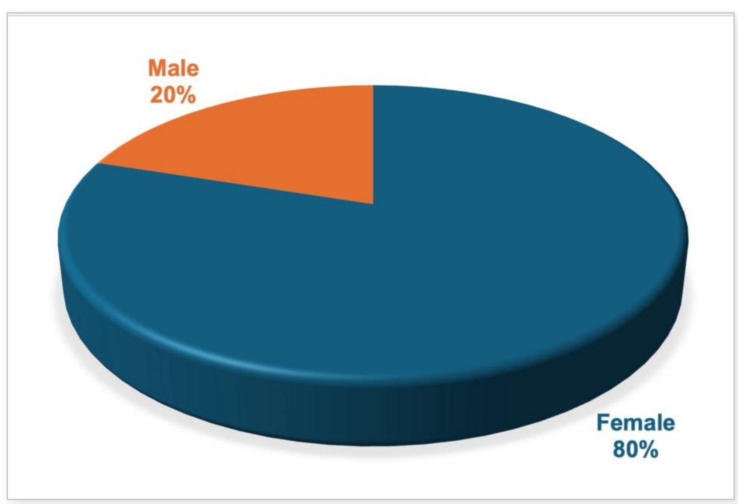

Figure 7. *Registered Students by Gender (n=20)*

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While the results of this study did not show a positive effect on anxiety reduction or success rates, the comments recorded in the survey did reveal that students who completed the survey at the end of the semester valued the active learning tools used in the course (see Table 1). These student comments are aligned with many of the benefits associated with active learning strategies in the literature such as: experiencing deeper learning and fostering critical thinking (Stevenson & Gordon, 2014), gaining self-confidence by developing a better understanding of the course material (Rao et al., 2002), enhancing the student learning experience (Bloom, 2009), greater engagement and agency in the learning process (Rivaz et al., 2015), and increasing a student's sense of belonging (Estrada et al., 2011; Pekary et al., 2021; Royse et al., 2020).

Since the present study and previous studies cited did not find reductions in student anxiety, it may be that the wrong experimental question was asked. Could it be that anxiety is a normal and necessary component of learning? The results of this study brought the Yerkes-Dodson Law to mind (Figure 8), which posits that peak performance is associated with a certain amount of stress (termed "arousal" in the graph).

It may be that the focus of this study should not have been on reducing stress but on assessing the effectiveness of the active-learning strategies used, including cooperative quizzes, to help students develop the metacognitive skills and growth mindset necessary to cope with the increased stress of an entry-level A&P course. The Yerkes-Dodson Law is often applied to reaching peak performance in competitive sports. In this setting, the tried-and-true approach for a coach trying to help athletes reach their peak performance is to provide the settings under which the athlete will compete (i.e., track, field, etc.), along with an effective schedule of repeated bouts of very specific training. Based on the comments offered by students in the semester-end survey, it may be that it was the components of the course mentioned by students in Table 1, and repeated weekly, that contributed most to their ability to succeed in the course. It may be that activating a certain level of social anxiety leads to activating personal responsibility to make changes and do something that moves the student in a positive learning direction. These questions offer fertile ground for new knowledge and understanding regarding the learning of science.

Limitations

One notable limitation of the present study is the amount of attrition during the semester that resulted in only 20 of the original 89 students competing the end-semester survey. The final *n* of 20 students meant that the ability of the statistical analysis to detect an effect was compromised and the risk of committing a Type-II error (failing to reject the null hypothesis when it is false) was increased. There are likely several factors that contributed to the high attrition rate including: being a community college student in STEM, which is associated with higher course attrition rates (Downing et al., 2020); students experiencing major life events (e.g. sudden, unexpected death of a close other), which occurs more frequently in the community college student population compared to university students (Anders et al., 2012); increased resistance to active learning strategies from students, which could have resulted in students disengaging from the learning process (Deslauriers et al., 2019; Hood et al., 2021); and the higher attrition rates reported in African American and LatinX students (Theobald et al., 2020). Another factor that probably contributed to student attrition was the number of hours per week spent working, leaving less time to devote to studying and learning. Figure 9 reveals that more than one-third of the students were working full-time (defined as ≥ 30/week).

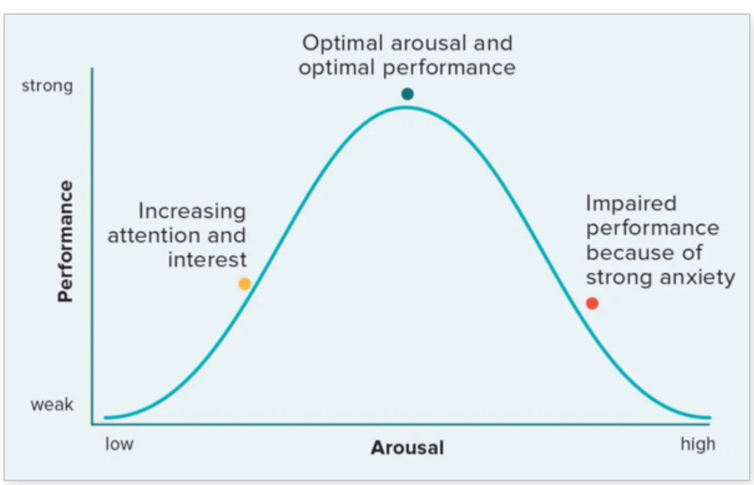

Figure 8. *The Yerkes-Dodson Law*

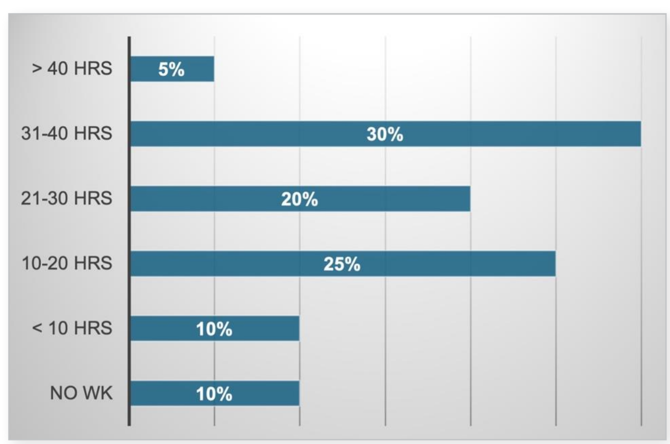

Figure 9. *Attending College While Working Full-Time (n=20)*

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Race, gender, and socioeconomic status are all factors that contribute to reduced time being available to study and learn in college (Wladis et al., 2024). One final factor that could have contributed to the high attrition rate is the fact that the course (BIO 150) does not require students to complete any science or laboratory prerequisite course work.

Conclusions

Collaborative quizzing may not decrease student test anxiety or improve success rates in a community college entry-level A&P course. Additional studies of community college A&P entry-level courses are needed to confirm or reject the results due to the low statistical power of the present study. While the effects of collaborative quizzing on student anxiety and success rates are not conclusive, the positive comments offered by students indicate that students perceived collaborative quizzing and the other active learning strategies employed in this course as a helpful component in their learning process.

About the Authors

Will Jonen Ph.D. is an associate professor at Delaware County Community College. He has taught human anatomy and physiology for the last 18 years and strives to support student learning using evidence-based instructional practices.

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Ron Gerrits Ph.D. teaches physiology and related courses at the Milwaukee School of Engineering. His professional interests are curriculum development and educational research.

Murray Jensen Ph.D. has been teaching anatomy and physiology for over 20 years and promotes the used of guided inquiry and cooperative group learning.

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EDUCATIONAL RESEARCH

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Effects of Supplementing the Deconstructive Process of Dissection with the Constructive Process of Building Muscles in Clay

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Abstract

Gross anatomy courses utilize cadaver dissection to teach identification, topography, and spatial relationships of organs. The deconstructive nature of dissection, however, focuses students' attention on the "big picture", followed by a discovery of details. This approach may be useful for many, however some students may prefer to build-up knowledge from the smallest details to the larger picture. Further, if a student can work through the deconstructive process of dissection, then mirror it in a constructive way, they are more likely to have a comprehensive understanding. To investigate if supplementing learning by dissection with a constructive activity would improve students' understanding, 233 undergraduate gross anatomy students were asked to build muscles in clay following their standard lecture and dissection periods. Prior to the clay activity, students watched lecture videos presenting information about muscle actions, completed in-class activities that required application of the information from the videos, and dissected the muscles. Students then took a pre-quiz designed to evaluate their understanding of four specific concepts: 1) origins and insertions, 2) actions based on location, 3) identification, and 4) spatial relationships. During a lab period after the pre-quiz, students built the muscles on a skeletal models. Students then took a post-quiz which evaluated the same four concepts. Students scored significantly higher after completing the clay activity (pre-quiz mean = 56.25%, post-quiz mean = 71.75% ($p < 0.0001$)). Student scores improved significantly in the areas of spatial relationships, origins and insertions, and identification. https://doi.org/10.21692/haps.2025.003

Key words: clay, art, constructivism, teaching methods, hands-on

Introduction

Challenges in learning anatomy

Learning anatomy presents unique challenges for the novice student. One of the greatest among these is the task of mastering the spatial and visual skills required to construct three-dimensional (3D) mental models. These mental models must be sound enough to be used to correlate structure with function in clinical applications that require critical thinking. Without a clear and accurate mental model and the ability to utilize it, anatomical knowledge and retention will not stand up to the challenge of application in future careers (Estai & Bunt, 2016; Toogood, 2017; Sugand et al., 2010; Turney, 2007). For many students, mastery and long-term retention of concepts in anatomical sciences requires unique approaches to studying and learning.

Unfortunately, many students approach learning gross anatomy with the strategy of rote memorization. This surface-level approach is especially prevalent when attempting to learn the vastly expansive and vocabulary-dependent area of musculoskeletal anatomy (HAPS Learning Outcomes, Module F, 1.1; Module G, 1.1, 7.1, 8.1-2, 9.1-2, 10.1). To identify basic structures, students often overlook the necessity of making connections, observing spatial relationships, and applying concepts. Instead, they spend an excessive amount of time creating flash cards and memorizing content in lieu of focusing on deeper understanding of key concepts that would allow them to deduce the location and function of structures. To learn more efficiently and retain knowledge, students must refocus their attention beyond structure identification and

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towards understanding attachments, muscle layering, and muscle functions. To do this, students must create 3D mental models to help them visualize spatial relationships. A more detailed mental model formed with better visualization may help students to understand concepts and patterns in musculoskeletal anatomy that could improve their knowledge and retention.

Methods in Musculoskeletal Anatomy Education

Numerous methods and approaches exist to teach musculoskeletal anatomy. These include models, software programs, two-dimensional (2D) images, written guides, and traditional cadaver dissection. Dissection has been the primary instructional method for hundreds of years (Azer & Eizenberg, 2007). Both students and anatomists view it as the "best fit" approach to achieving learning outcomes (Kerby et al., 2011). However, none of these learning methods, in isolation, is recommended as the most efficient for teaching gross anatomy (Ghosh, 2017).

Although the benefits of dissection are undeniable, some aspects of the dissection process can present challenges to student learning. Dissection is a process that requires students to start with an overarching concept or system, then add detail as they move from superficial to deep structures. This process may present challenges to students for various reasons. For example, students are unlikely to have any prior experience with dissection, and therefore lack an understanding of basic characteristics of tissues and structures. This lack of experience contributes to misidentifying tissues (for example, nerves versus connective tissue or arteries versus veins), and it often leads to the destruction of crucial structures during dissection. Unfortunately, once a structure is removed or destroyed, the area is no longer an accurate representation.

Specifically, regarding the musculoskeletal system, dissection requires students to have a simultaneous understanding of both the skeletal and the muscular anatomy. Students must be skilled in spatial orientation to visualize bones deep to skin, muscles, and connective tissue as they move through the dissection. Only students with very specific and well-organized learning styles and methods may be successful in overlying these "big picture" systems, integrating them, and finally adding detail through dissection.

Art-Based Learning in Musculoskeletal Anatomy Education

Many supplemental techniques have been explored to encourage construction of knowledge within the musculoskeletal system through engagement and visuospatial thinking. Haptic, art-based practices including drawing, body painting, and sculpting have all been explored as supplementary methods to learning and teaching the musculoskeletal system with positive results (Backhouse et al., 2017; Lerner, 2007; Bareither et al., 2013; Cookson et al., 2018; Keenan et al., 2017). As an example, Shapiro et al. (2023) utilized haptic surface painting (HSP) to improve anatomical understanding and spatial awareness of the musculoskeletal anatomy of the forearm and hand. Participants in this study noted that their understanding of three-dimensional anatomy was focused, supported and enhanced due to the HSP method's ability to help them visualize and interact with their learning. Further, Reid et al. (2018), used the Haptico-Visual Observation and Drawing (HVOD) method to explore students' ability to generate conceptual representations and connections when learning. Participants reported that the HVOD method led to better visualization, which resulted in improved understanding of three-dimensional musculoskeletal structures, as well as improved retention.

Anatomy Education Using Clay Building

Building structures with modeling clay is a technique that has become increasingly popular (Kooloos et al., 2014; Bareither et al., 2013; Waters et al., 2005; Motoike et al., 2009; DeHoff et al., 2011). This method allows students to start with the skeletal system and layer on structures, allowing them to actively experiment while constructing their own knowledge. Building muscles in clay allows students to adjust and correct missing, incomplete, or inaccurate visuospatial information gained during dissection. The reproducible nature of this activity also means that students can review structures by removing and replacing clay as they build their knowledge.

The tactile aspect of clay modeling makes it an appropriate complement to traditional dissection. Studies have shown that haptic feedback while exploring 3D objects results in better 3D understanding than does visual feedback alone (Jones et al., 2005; Naug et al., 2011).

Studies such as Waters et al., 2005; Motoike et al., 2009; DeHoff et al., 2011 compare the effect of clay modeling versus traditional dissection on exam performance. Students in these studies were separated into either a cadaveric dissection group or a group who learned using clay modeling. The studies found that there was either no significant difference in the exam scores between the two groups (Waters et al., 2005 and DeHoff et al., 2011 – high order scores), or a significantly better performance from the clay group (Motoike et al., 2009; DeHoff et al., 2011 – low order scores).

One study (Bareither et al., 2013) assessed the effects of combining dissection with supplemental instruction—either clay modeling (intervention) or a written module (control) — on exam performance and retention. These researchers found that student scores from the intervention group were significantly higher than those of the control group, indicating an additive effect from the supplemental activities.

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Theoretical Framework

Multiple educational theories can be used to explain and overcome the challenges to learning anatomy with dissection alone. Constructivism is a learner-centered theory that describes the learning process as a building process wherein the student begins at a foundational level and actively adds detail to create a better understanding (Dennick, 2008). This framework can be used to support the use of building muscles in clay as a tool for students to build upon a foundational knowledge of the skeletal system. Students begin with a skeletal model, then work to build their knowledge of muscle attachment and spatial relationships on top of that model. When combined with the traditional dissection process, the application of building muscles in clay is further supported by Kolb's experiential learning theory. This framework describes the learning process as a repeated cycle of constructivist learning rooted in participation and experimentation (Kolb, 1984). Learners first engage in a concrete experience (i.e. dissection), and then reflect on and experiment with what they have gained in that experience (i.e. building the same muscles in clay) to construct their understanding.

Research Aims and Hypotheses

Previous studies have identified a positive impact of incorporating clay building techniques on overall exam scores. However, a careful review of the existing literature did not reveal any studies evaluating the effects of supplementing dissection with clay modeling on specific anatomical concepts. Identifying specific concepts affected by clay modeling activities could help educators align interventions with distinct learning outcomes, assessments and styles.

This study aims to fill the above-mentioned gap in the literature by first determining whether supplementing cadaver dissection with a clay muscle-building activity would affect student performance in the following four categories: muscle identification, bony attachment, spatial relationships, and action based on location. Secondarily, this study will obtain and evaluate student opinions about the value of the clay modeling activity on their learning.

Materials and Methods

Study Population

Many Texas A&M University Biomedical Sciences (BIMS) graduates pursue postgraduate training in healthcare fields including human medicine, veterinary medicine, nursing, or dentistry. At the time of this study Biomedical Anatomy (VIBS 305) was a required 4-credit hour course for all students in the BIMS undergraduate program. The 15-week course included two required 50-minute lectures and two 110-minute laboratories each week. Laboratory sections consisted of 70 to 96 students. Each section was then subdivided into teams of four for dissection. Each team dissected a canine cadaver for comparative study of human and veterinary anatomy. Students dissected the musculoskeletal, cardiovascular, digestive, and urogenital systems and the major peripheral nerves.

This study was conducted during the fall semester of 2017 and the spring semester of 2018. Total enrollment during the study was 329 students. All students enrolled in VIBS 305 were required to participate in the clay modeling activity and take unscheduled quizzes as part of the course. Of the 329 enrolled students, 233 (70.8%) completed all components of the study and consented to allow us to use their data. The project was approved by the Institutional Review Board of Texas A&M University, and informed consent was obtained from all participants (IRB2015-0610D). Student demographics are summarized in Table 1.

Characteristics/cohort	Fall 2017	Spring 2018
Sex (number)		
Male	55	20
Female	100	58
Age in years (mean)		
Male	21.1	20.8
Female	20.7	20.6
Classification by credit hour		
Junior	21	4
Senior	134	74

Table 1: *Demographic data of students enrolled in Biomedical Anatomy and consenting to participate in the study. The distribution of male and female was similar for both semesters with more females than males enrolled. The mean age was not statistically different between semesters or sexes. The median age was 21 years. Most of the students (89.3%) were seniors.*

Activity

Before participating in the clay modeling activity, students had completed all lectures, lecture activities, and dissections pertaining to the musculoskeletal system of both the thoracic limb and the pelvic limb. Students completed the clay activity in groups of 3-5 within a two-hour lab period. Each group was provided with one Maniken (human skeleton in quadruped position) and one Caniken (canine skeleton) Anatomy in Clay model from Zahourek Systems Inc., Loveland, CO, shown in Figure 1. Due to the limited number of skeletal models, the clay muscle building activity occurred during two consecutive lab periods of the same week. Two students from each dissection team were randomly assigned to attend the first session and the remaining two students were assigned to the second session.

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All students assigned to the first clay modeling session completed their quizzes at the beginning of lab and then moved into the adjoining room to complete the activity. Students assigned to the second session completed the quiz approximately 20 minutes later and then continued with the regularly scheduled dissection. Students were allotted the remaining lab time to complete the dissection of peripheral neurovasculature or complete the clay modeling activity. Two days later, during the next scheduled lab period, the students assigned to the second session completed the clay modeling activity while the other students continued with regularly schedule dissection.

Both clay modeling sessions began with a brief introduction. Although the activity was designed to be self-paced and self-directed, instructors with experience building clay muscles were available to answer questions. Oil-based modeling clay, sculpting tools, anatomy atlases, and a detailed packet with color images and instructions were provided. Students were encouraged to attempt to build at least some of the muscles on both sides.

While students could choose whether to build muscles on the human, the canine, or both, they were informed that they would be responsible for all information in the accompanying packet, which included both species. Since students had studied only the canine bones in detail, labeled images of the relevant bones of the human skeleton (pelvis, femur, tibia, and fibula) were provided for reference. The rest of the packet indicated the origin, insertion, and major actions of each muscle. Illustrations and other images from relevant textbooks and Anatomy in Clay materials were also provided for visual reference. Descriptions and images were in order from the deepest to the most superficial muscle. This order was not explicitly stated. For the activity, 16 muscles from the hip and thigh were chosen. All differences and significant similarities between species were explained in the packet.

Assessment of Knowledge

Before session one of the clay modeling activity, all students were given a pop quiz to assess their base knowledge of pelvic limb musculoskeletal anatomy. The quiz was administered during their assigned lab time. In keeping with the familiar lab practical exam format, students were allowed one minute per question. Both quizzes consisted of eight questions, two for each of the content areas. Questions were designed to assess each of the four basic content areas:

1. Muscle identification on a cadaver (ID) (HAPS Learning Outcome, Module G, 7.1, 8.1)
2. Bony origin of a specific muscle (Origin) (HAPS Learning Outcome, Module G, 7.1, 8.1)
3. Spatial relationship of a specific muscle to underlying bone (SR) (HAPS Learning Outcome, Module G, 8.1)
4. Muscle action based on where it crosses the joint (Action) (HAPS Learning Outcome, Module G, 7.1, 8.2, 10.1)

Structures on bones were tagged using tape, and muscles were tagged using colored string. For each category (except ID), one question was human-specific, and one was canine-specific. Both ID questions were asked on a canine cadaver because no human cadavers were available. Questions targeting ID, SR, and Action were free response, while questions targeting Origin were multiple choice.

The final phase of the study occurred five days later, during the next regularly scheduled lab class, when a second pop quiz (post-quiz) was administered to all the students. The concepts, format, and logistics of the post-quiz were the same as in the pre-quiz. However, the specific structures that were tested differed slightly.

Figure 1: *Caniken and Maniken Skeleton Models. This figure depicts students placing clay muscles onto the provided skeleton models. The Caniken is on the left, and the Maniken is on the right.*

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Assessment of Student Perceptions

A survey to assess the students' perceived impact of the clay modeling activity was administered during the lecture period following the clay activity and the post-quiz.

The survey consisted of 11 statements to which the students were asked to respond using a 5-point Likert scale ranging from "Strongly Agree" to "Strongly Disagree." The questions covered multiple topics, including whether students thought the model helped them see actions and understand spatial relationships of muscles, forming and placing muscles on a model was beneficial, and the activity was easy to do.

Data Analysis

Both qualitative and quantitative data were collected. Statistical analyses were conducted using JMP 16 Pro (SAS Institute). Quiz data were analyzed using the Shapiro-Wilk test, which indicated data were not normally distributed. Therefore, overall means between the pre- and post-quiz were compared using the Wilcoxon signed rank test to at least a type I error rate of 5% ($P < 0.05$). Differences between pre- and post-quiz performance by question category were also compared using the Wilcoxon signed rank test with a type I error rate of 5% ($P < 0.05$).

Results

Comparison of Mean Pre- and Post-Quiz Scores

Before starting the clay modeling activity, all students completed a pelvic limb musculoskeletal pre-quiz. The mean score was 4.5 out of 8 points with SEM of 0.1029 (N=233). A week after completing the clay modeling activity, students completed a post-quiz. The topics were the same, but the actual questions were slightly altered. Wilcoxon signed rank test analysis determined scores were significantly higher ($P < 0.0001$) on the post-quiz. The mean score was 5.74 out of 8 points with SEM of 0.1028.

Comparison of Student Performance by Question Category

Both the pre- and post-quiz consisted of eight questions evenly divided among each of the four categories of interest: muscle identification (ID), bony attachments (Origin), spatial relationships amongst muscles and bones (SR), and muscle action based on location (Action). Pre- and post-quiz scores were then analyzed based on the four question categories. Statistically significant increases in scores ($P < 0.0001$) were noted for questions concerning ID, Origin, and SR. However, the mean did not change significantly for correctly answered questions targeting Action (Figure 2).

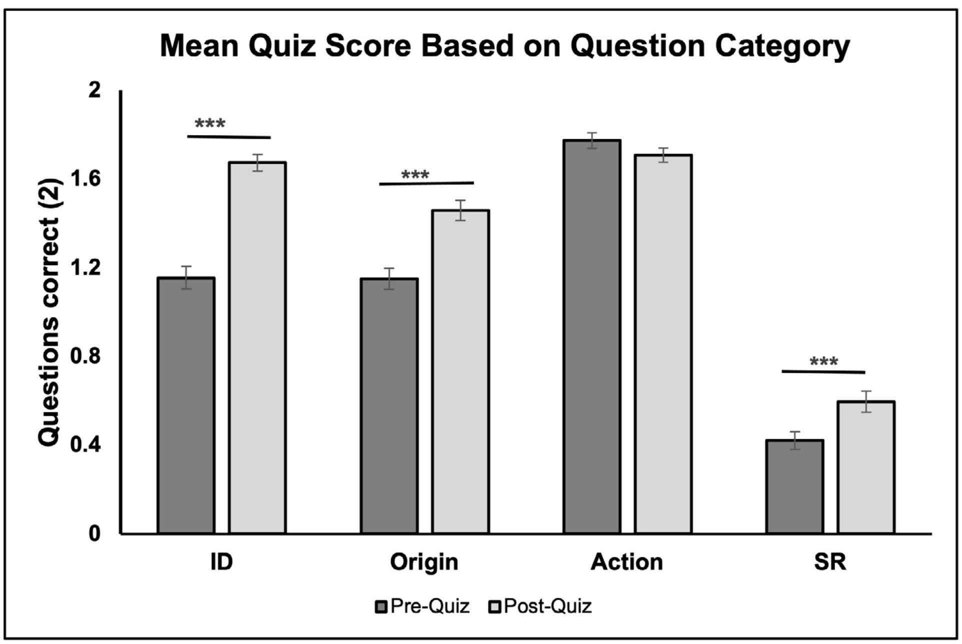

Figure 2. *Quiz questions were divided evenly among the four question categories: ID, Origin, Action, and SR. Mean scores per category (± SEM) before the clay modeling activity were compared to scores post activity. (n=233). ***P<0.0001 pre- to post-quiz for ID, Origin, and SR. The mean was unchanged for the action category.*

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Categories were then compared based on the students' overall performance within the category. Questions regarding Action had the highest percentage of students answering both questions right on both the pre- and post-quiz (83% and 73% respectively). Only 5.6% of the students were able to answer both SR questions correctly on the pre-quiz, which increased to 21% on the post-quiz. The percentage of students answering both Origin questions correctly increased from 11% on the pre- to 57% on the post-quiz (Figure 3).

Student Attitudes Toward Muscle Building Activity

We surveyed students to determine their views about how building muscles out of clay and then placing them from deepest to most superficial on a skeletal model affected their learning of foundational musculoskeletal concepts. The haptic aspect of the activity was perceived as beneficial. A majority strongly agreed or agreed that they benefited from placing muscles on the skeleton (65.7%) and working with physical materials (58.3%). Similarly, a majority strongly agreed or agreed that the model helped them to understand the location of muscles relative to one another (61.3%), see specific origins and insertions (56.7%), and mentally use the position of the muscle relative to the flexor angle to deduce action (60.5%) indicating they perceived value from the visual and spatial aspect of the activity. Students were undecided (39.1%) as to whether the model helped them understand muscle belly size relative to function. Overall, student opinions were more evenly split regarding whether making clay muscles was easy to do (Table 2).

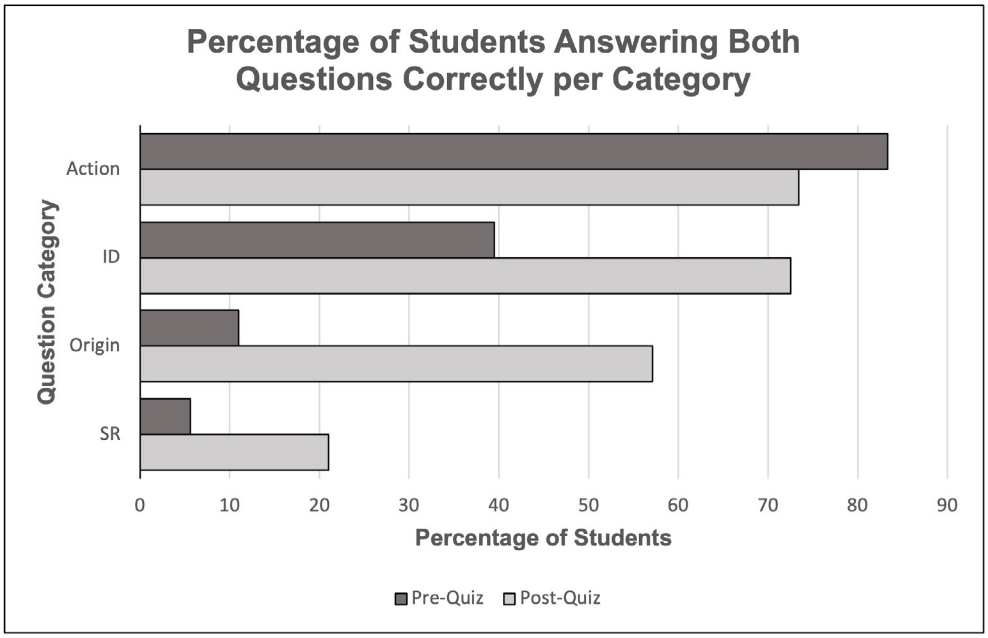

***Figure 3**. The percentage of students correctly answering both questions varied according to the category. A higher percentage of students was able to correctly answer both action questions while a low percentage correctly answered the questions regarding spatial relationships of muscles.*

Survey Question	Strongly Agree	Agree	Disagree	Strongly Disagree	Undecided
I benefited from being able to place muscles on the skeleton.	33.5%	32.2%	15.9%	17.6%	0.9%
This model helped me to understand the location of specific muscles relative to one another.	27.0%	34.3%	18.0%	15.0%	5.6%
I benefited from being able to work with physical materials.	27.0%	31.3%	14.6%	16.7%	10.3%
This model helped me to be better able to mentally use the location of a muscle relative to the flexor angle to deduce the muscle's action.	29.2%	31.3%	17.6%	16.7%	5.2%
This model helped me to see specific origins and insertions.	30.9%	25.8%	15.5%	19.3%	8.6%
This model helped me to see actions of specific muscles.	23.4%	30.7%	20.8%	13.0%	12.1%
I benefited from being able to form muscles out of clay.	14.6%	33.5%	22.7%	10.3%	18.9%
I would encourage my friends learning gross anatomy to use his method to study.	15.0%	30.5%	24.9%	9.0%	20.6%
This model helped me understand the relationship of opposing muscle pairs	12.0%	30.5%	23.2%	8.6%	25.8%
This model helped me to understand muscle belly size relative to its function.	10.7%	23.2%	21.0%	6.0%	39.1%
Making muscles out of clay was easy to do.	8.2%	33.0%	31.8%	9.9%	17.2%

***Table 2**: Student perceptions toward building clay muscles to learn specific musculoskeletal concepts. Students were asked to provide feedback about the activities effect on learning spatial relationships, muscle actions, and origins and insertions. They were also asked to rate how easy it was to make the muscles.*

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Discussion

The clay muscle-building activity explored in this study is an example of supplemental instruction that could help students more efficiently learn and retain anatomy concepts in a dissection-based course. This method redirects students' focus from rote memorization to more critical thinking and concept-based learning. Pedagogical methods that incorporate active learning and engagement are hailed as effective ways to promote mastery of material and supported by literature and many educational models (Backhouse et al., 2017; Lerner, 2007; Bareither et al., 2013; Cookson et al., 2018; Keenan et al., 2017; Shapiro et al., 2023). The muscle building exercise required active participation as students were required to physically create the muscle from modeling clay and then actively attach the muscle to its origin and insertion sites. The significant improvement in quiz scores after building muscles in clay could indicate that the activity helped students refine their 3D mental models of various musculoskeletal structures as well as reinforce muscle identification.

Three of the four content areas tested (ID, Origin, and SR) showed significant improvements from pre-quiz to post-quiz. This difference was made apparent by comparing the percentages of students who correctly answered both questions within each category. The only content area that did not have a significant improvement was muscle actions based on location. However, this area was the highest performing across both the pre- and post-quizzes. There are a few possible reasons for this finding. Determining a muscle's action based on where it crosses a joint is a foundational concept that is covered early in the course. Students had already been assessed multiple times regarding this concept as it related to the shoulder, arm, and forearm. Students most likely had already mastered the concept using other study methods prior to the clay activity. It is also possible that, because muscle action is a dynamic concept and the clay activity offered only static skeletal structures, there was insufficient correlation between the concept and activity to significantly affect the students' learning.

Student scores improved significantly for both Origin and ID. Like the concepts regarding action, these concepts were introduced early, leaving students ample opportunity to refine their mastery and study methods regarding these concepts. However, it seems that the clay activity still had an impact on performance in these areas, possibly because students were transferring concepts they had learned in reference to slightly different structures.

In contrast, the lowest performing content area was the spatial relationship of a specific muscle to underlying bone. This concept is not specifically addressed in the first part of the course, nor did previous tests or quizzes contain any questions focusing on this topic, which may be the reason for this finding. However, it does seem that the clay activity improved mastery in this area, as the percentage of students answering both questions correctly increased from 5.6% to 21%. Some of this improvement, however, could be attributed to introducing spatial relationships in the pre-quiz, thus prompting the students to pay more attention to the concept.

The physicality and interactivity of the clay muscle-building activity most likely contributed to the improvement in student understanding. The benefits of a physical model over 2D images, and even digital resources, have been shown in multiple studies (Wainman et al., 2020; Khot et al., 2013; Preece et al., 2013). Stereopsis, haptic feedback, and transfer-appropriate processing all contribute to the superiority of a physical model over 2D key view images (Wainman et al., 2018; Wainman et al., 2020). The clay muscle-building activity provides all of these, like a traditional physical model, but also incorporates interactivity, which enhances the learning experience (Pereda-Nuñez et al., 2023). During this activity, students were able to visualize all the layers of muscles and underlying structures from any perspective, and in any order – helping them to create a more accurate mental model. In addition, the haptic feedback from physically creating and attaching muscles allows students to isolate and focus on specific structures and concepts. Finally, both dissection and the clay activity provide a means to physically manipulate and navigate structures. Dissection accomplishes this with the systematic removal of layers, while the clay activity accomplishes the same with the systematic build-up of layers – making it particularly appropriate as a supplement for a dissection-based course.

The survey responses regarding the students' perceived impact of the building muscle in clay activity indicated they perceived benefit from correctly placing the muscles on the model, working with physical materials, and using the model to understand the spatial relationship of one muscle to another. They also agreed that the model helped them to see the specific origins and insertions. The student responses were more evenly split regarding their view of how easy it was to make the muscles out of clay.

The item on the survey that the most students disagreed or strongly disagreed with (41.7%) was "making muscles out of clay was easy to do". Clay manipulation can be difficult and requires time to learn. Warming and molding the clay can compound a negative response for students who already do not see the activity as beneficial, who do not see themselves as "artistic," or both.

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Limitations

As this study was conducted using the single group pre-experimental research design, the quiz improvement, in whole or part, could be attributed to other factors such as the testing effect, maturation, or history (Marsden & Torgerson, 2012). However, students were exposed to all relevant material both in lab and in lecture prior to the pre-quiz. They had also practiced applying the material with in-class assignments and activities. Additionally, the post-quiz was given only days after the pre-quiz and the clay activity. Students did not have a substantial amount of time for further study. It is the researchers' experience that students do not devote a lot of time to studying as far as two weeks away from the next major exam, which was the time during which this study was conducted. Students were also unaware that there would be a second quiz, further decreasing the likelihood that they put extra effort into studying the material outside of class time. A likely explanation for the improvement in quiz scores is that building muscles required students to experiment with structures they had just studied from a new perspective. Students also had to physically visualize, and construct muscles based on foundational knowledge, instead of memorizing a key view or a list of attachments.

One issue observed during the activity was that many of the students did not recognize the value in completing it. They viewed it as an art activity that was taking the place of their dissection time. Students tend to prioritize material that they expect to be on an exam or otherwise directly affect their grade in the course. After their first practical exam, students realized the importance of completing the dissection and having time to study the cadaver when preparing for the exam. Although the clay activity was designed to minimally impact dissection time, students felt they should have been dissecting. This situation could be avoided in the future by explaining to the students the expected benefits of the activity and showing them the improvement in quiz scores from previous studies. In addition, future implementations of this activity could include a graded assessment in which students must demonstrate their ability to correctly place muscles on a skeletal model.

Another limitation was the limited number of models and the amount of time available for students to complete the activity. Because students learn in different ways and at different paces, it would be ideal for each student to work individually on their own model with ample time to focus on concepts and structures they feel needed the most attention. This would also eliminate the pressure from group members to create a more "artistic" rendering. Unfortunately, scheduling and the cost of the skeletal models limited our ability to meet this need for students in the current study.

Conclusion

This study helps demonstrate the benefit of supplementing traditional methods of anatomical instruction, such as lecture and dissection, with a physically interactive and constructive activity. We found that the clay muscle-building activity significantly improves student performance, specifically regarding concepts related to spatial relationships amongst muscles, identification of specific structures, and muscle attachments.

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Anatomy of the Female Reproductive System and its Association with the Biomechanics of Parturition

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Abstract

Anatomy educators use many tools to make their lessons clear and memorable. To do so, educators may describe the spatial relationships, physiology, and clinical correlations of the anatomical structures being studied. Explanations of the biomechanics of anatomical structures are another tool that some anatomists may be hesitant to incorporate but that can be beneficial for student comprehension. Linking anatomy to biomechanics can engage students by exploring the interactions among common anatomical structures. One topic that is ripe for connections between form and function is the process of childbirth, or parturition. This article serves as both a guide and a review for anatomists approaching the female reproductive system with function in mind. The topics include 1) the roles of ligaments, 2) the process of cervix dilation and effacement, and 3) expulsion of the fetus. Connecting the anatomical structures of the female reproductive system with their roles in the biomechanics of childbirth may be a useful tool for student comprehension of this challenging material. This article serves as an example to encourage other anatomists to make biomechanics more palatable to anatomy educators. https://doi.org/10.21692/haps.2025.004

Key words: biomechanics, childbirth, ligaments, uterus, cervix

Introduction

Anatomy is intimately related to the study of biomechanics. One cannot exist without the other. To study biomechanics, one must first understand anatomical structure. Similarly, to understand why certain anatomical structures are shaped or oriented in a certain way, it is important to understand the function that the structure fulfills. While these functions are often highlighted when examining the structure's physiology, they are less well recognized from a biomechanical aspect. Biomechanics is the study of internal and external movement of the body, a natural extension of anatomy. It helps us understand activity throughout the body, as well as the requirements and constraints on an anatomical structure's shape, material, composition, and arrangement.

Although anatomists appreciate that form and function are intimately related, it can be a challenge to tie these ideas together for students. It is common for anatomy courses to include minor biomechanics topics, such as rib motion during respiration and parts of the gait cycle; however, this content varies with each instructor and the content covered. Because of this, there is no guarantee that students will have a uniform exposure to biomechanical concepts. By including common biomechanical scenarios in an anatomist's training, one can ensure that students studying anatomy are applying it to common functions (e.g., mastication, digestion, gait, parturition). Anatomists entering the workforce can then apply and communicate knowledge of biomechanics to their students as an anchor point for anatomical knowledge, in a similar manner to including the use of clinical correlates (Dusseau et al., 2008).

For some anatomists, biomechanics seems inaccessible; physics is often taken early in an academic career and is often not a required course to become an anatomy educator (Balta et al., 2019). Inadequate training or delayed use of knowledge may make anatomists and clinicians hesitant to broach biomechanical topics in their anatomy teaching. Educators need to address this disconnect between form and function to help budding anatomists answer the "why" questions. Why is this bone shaped this way? Why is this tendon thicker than that one? Why are these muscle fibers oriented in this direction? These questions do not

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necessarily require complex equations or an in-depth understanding of physics. By outlining the biomechanics of common operations of the human body, this review aims to make biomechanics palatable to the learning anatomist. Armed with this information, current and future educators, physicians, and scholars can then tackle topics such as childbirth, gait, or mastication head-on with the confidence that they can effectively apply their knowledge of biomechanics to their own anatomy courses and lectures.

To include biomechanics topics, anatomists need resources on human anatomy biomechanics. This will simplify blending functions of structures with what often becomes the rote memorization of anatomy. Indeed, many teaching anatomists study functional morphology and blend anatomy and biomechanics as part of their research programs. There is a great wealth of biomechanical knowledge within the anatomy community with many experts who can help directly address this knowledge gap. The goal of this paper is to inspire others to share their areas of specialty or interest with the rest of the anatomy teaching community, leading to a more comprehensive approach to anatomy education and interdisciplinary thought processes. Creating resources specifically for anatomists, by anatomists, can help train the next generations of educators.

To launch this call for human anatomy biomechanics-focused resources, this biomechanical review has explored an anatomy topic that is helpful to discuss in the context of movement and is ideal for sharing with anatomy professionals. This article examines the biomechanical role of female reproductive structures during parturition (childbirth), a topic that certainly benefits from relating the structure and biomechanical movement but is rarely covered in this light. While there may not be specific lecture time devoted to this topic, educators can present what is most pertinent to their student population, perhaps as a detail in lecture to help understand an anatomical relationship or as a discussion point in the laboratory.

The current state of anatomical discourse regarding childbirth, often taught in the reproductive section of anatomy courses, covers the basic spatial relationships of structures including the uterus, cervix, vagina, ligaments, pelvis, and muscles of the pelvic floor (Balta et al., 2019). But why are these ligaments there? Why should students care about the different layers of the uterus? These questions can all be answered when one considers the process of parturition in the female reproductive system. Students struggle in this area, and the pelvis can often be one of their least favorite regions to study (Hall et al., 2018; Kramer & Soley, 2002). Putting these structures in a biomechanical context may help engage the students and aid their learning process.

The intention of this article is to make the biomechanics of childbirth accessible to anatomists and applicable to students from undergraduate to professional populations. The aim is to provide integrated, as well as structure-specific information, so that educators can pick and choose what might be most helpful to their learners – no matter the level. The following sections will cover an overview of parturition to establish a base level of knowledge and then delve into the three biomechanics-related topics and the anatomy involved: 1) the role of ligaments, 2) pressure without movement during cervical dilation and effacement, and 3) pressure generation with movement during the expulsion phase of childbirth.

Stages of childbirth overview

Before taking an in-depth exploration of the changes occurring in female structures during pregnancy and parturition, it is salient to first review the stages of childbirth. From the perspective of changes in the cervix and its interactions with fetal structures, there are three key stages. These stages are 1) Effacement & Dilation, 2) Expulsion, and, 3) Delivery of the Placenta. During the first stage of dilation and effacement, the cervix undergoes the most change by shortening vertically and widening horizontally to allow fetal structures to pass through the birth canal. In the second stage, the fetus actively passes from the uterus to the outside world. The last stage, which will not be covered, is the expulsion of the placenta from the uterine wall (Cunningham et al., 2018). Throughout these stages, specifically in the first and second stages, there is a large focus on the uterus and its varied contractions. Next, individual structures of the female pelvis and reproductive system during parturition will be discussed in greater detail.

The Role of Ligaments

Ligaments within the pelvis are often difficult to visualize during dissections and in images. The pelvis is a small space that is filled with a tremendous amount of neurovasculature, musculature, and organs. This struggle to visualize these structures often leads to a lack of interest or ability to fully understand their positioning and function (Kramer & Soley, 2002; Smith et al., 2014). Ligaments in the female reproductive system, specifically the round, uterosacral, and transverse cervical, are the ligaments that are addressed here. Many ligaments in the body attach bone to bone but, in the female reproductive system, these ligaments attach the uterus and cervix to the mons pubis and bones of the pelvis and sacrum. These stable structures allow the uterus to grow and involute while remaining spatially controlled within the pelvic and abdominal cavities. All of these ligaments undergo significant forces throughout pregnancy and childbirth to direct, support and limit the growth and movement of the uterus during pregnancy and parturition (Grimm, 2016; Rivaux et al., 2013).

While they are called "ligaments", it is important to note that these are not homogenous structures (Kaplan et al., 2011). Each ligament's morphological features reflect its specific

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function, with a distinct composition and arrangement. The ligaments attached to the uterus and cervix undergo tensile forces that are applied along the long axis of the ligaments, in opposite and opposing directions (Figure 1). The pulling motion lengthens and thins the ligament as force increases (Grimm, 2016).

As the uterus increases in size during pregnancy, it is stabilized by the surrounding ligaments, reminiscent of a tethered hot air balloon. The transverse cervical ligaments, also referred to as the cardinal ligaments, resist lateral movement as well as anterior and posterior malpositioning of the cervix and uterus. The ligaments achieve uterine and cervix stability via their connections laterally to the ossa coxae (Baah-Dwomoh & De Vita, 2017). The uterosacral ligaments undergo tensile forces to resist the anterior movement of the uterus as it grows larger throughout pregnancy (Figure 1). Force applied to the uterosacral ligament increases its stiffness to help resist the increased force as the uterus increases greatly in size (Martins et al., 2013). The composition of these ligaments includes connective tissue interspersed with nerve elements and blood vessels, along with some adipose and lymphatic tissue (Ramanah et al., 2012). Both the uterosacral ligaments and the round ligaments also have smooth muscle components; however, the uterosacral ligament is stiffer and stronger than the round ligament due to abundant collagen and elastin (Martins et al., 2013); Ramanah et al., 2012. The composition of the round ligament (Figure 1) reflects its lack of strength and stiffness, allowing for large length changes as it is extended during pregnancy, undergoing far more strain than the uterosacral ligaments (Rivaux et al., 2013).

The round ligament is an integral part of the controlled growth and movement of the uterus during pregnancy. As the uterus grows both superiorly and anteriorly, the round ligaments, which attach to the superolateral surface of the body of the uterus on either side, undergo tremendous tensile force to resist upward motion of the growing uterus (Grimm, 2021). Tensile force is a result of the ligament being pulled in opposite directions, lengthening the ligament. The round ligaments, specifically, are pulled superiorly by the expanding uterus as well as inferiorly by its more stable attachment to the mons pubis. This tensile force increases continually as the uterus expands. During active childbirth, the buildup of tensile force helps to pull the superior portion of the uterus inferiorly, increasing intrauterine pressure, compressing the cervix and, eventually, expelling the fetus from the uterus (Mahran & Ghaleb, 1964). The attachments to the fundus and the mons pubis are often what cause inguinal pain during late pregnancy as the tensile forces continue to build (Grimm, 2016).

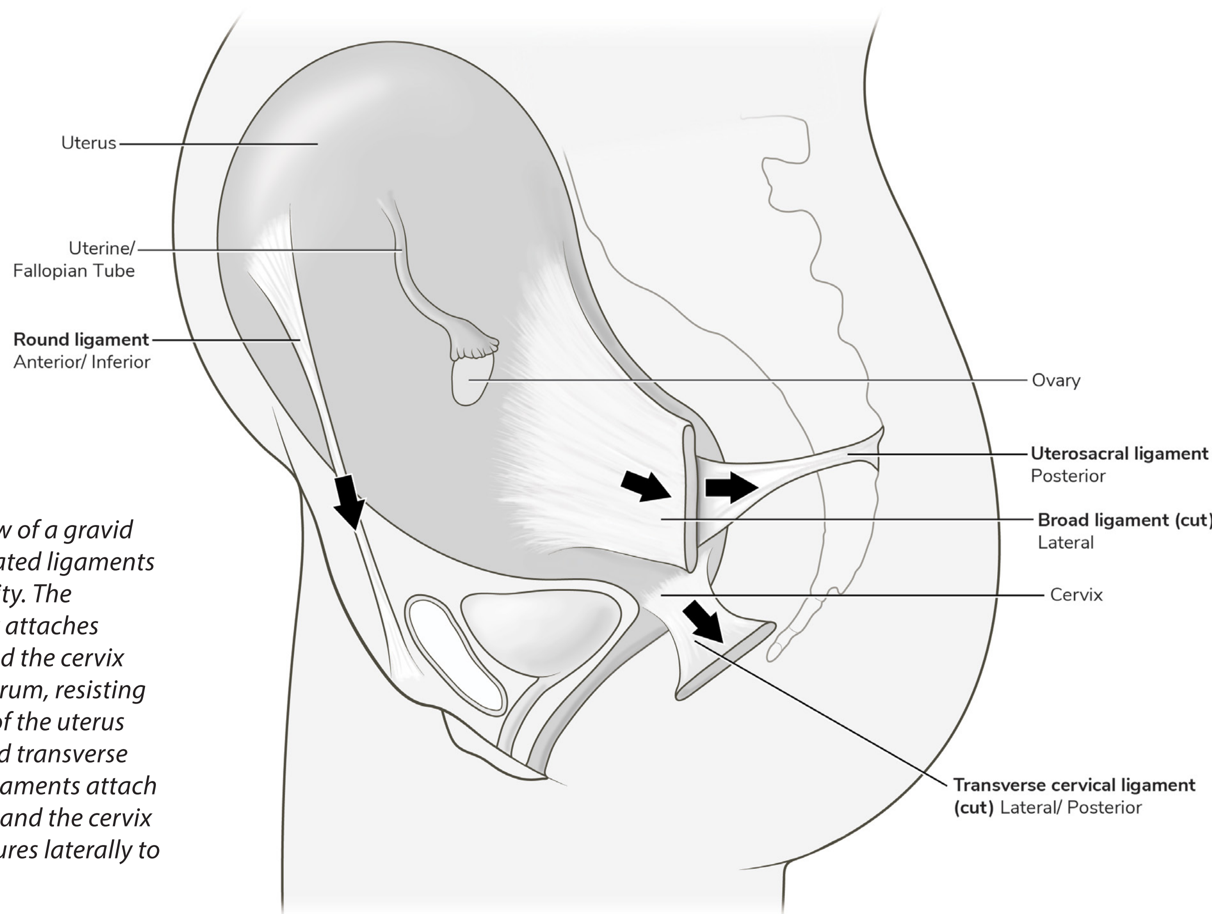

Figure 1. *Lateral view of a gravid uterus and its associated ligaments within the pelvic cavity. The uterosacral ligament attaches the inferior uterus and the cervix posteriorly to the sacrum, resisting anterior movement of the uterus and cervix. The paired transverse cervical (cardinal) ligaments attach to the inferior uterus and the cervix and pull these structures laterally to the os coxae.*

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Contrary to its name, the round ligament of the uterus is also known as the round muscle. The round ligament is a remnant of the embryonic gubernaculum and contains blood vessels, nerve fibers, collagen, as well as smooth and skeletal muscle fibers along with a low elastin content (Kaplan et al., 2011; Mahran, 1965; Mahran & Ghaleb, 1964). The complex arrangement of collagen combined with minor amounts of elastin allows for strength while resisting the upward pull exerted by the uterus. This ligament creates slow-wave contractions during pregnancy and childbirth due to its nervous and muscular combination to assist in the downward movement of the uterus (Mahran & Ghaleb, 1964). These slow-wave contractions are essential in creating additional downward forces on the fetal structures while pulling the uterine walls back into their original position to aid postpartum involution of the uterus (Figure 1).

When teaching about the female reproductive structures, we suggest including a figure of a gravid uterus with the associated ligaments, such as Figure 1. We have found real world comparisons, such as the uterine ligaments being like hot air balloon tethers to be helpful with undergraduate student populations. Visualizing how the ligaments collectively hold the uterus in place anteriorly, posteriorly and laterally may help students remember the names and positions of each ligament. Details about the composition of the round ligament and its role in childbirth can also accompany discussions of round ligament pain, often brought up as a clinical correlation.

Pressure without Movement during Cervical Effacement and Dilation

The uterus is the prime mover of parturition. The fetus must pass through comparatively small openings. To expel the fetal structures, most notably the head and shoulders, through the pelvic outlet, cervix, and vagina, the body cannot rely on gravity alone. Realizing this reality, it is key to understand the mechanics behind the contractions of the uterus and their results on the fetus and the cervix during parturition. The uterus is a multilayered structure consisting of the endometrium, myometrium, and perimetrium. The innermost endometrium consists of two layers called the functional and basal layers; the myometrium is principally comprised of smooth muscle; the perimetrium is a delicate outer later (Ameer et al., 2022). The muscular myometrial layer of the uterus is the driver of all three stages of labor. These smooth muscle fibers are not well organized in layers, as in the digestive tract; however, there are both circular and longitudinal muscular fibers making up this portion of the uterus (Figure 2). These fibers are arranged longitudinally from the body to the cervix, across the fundus, and projecting inferiorly from the uterine tubes (Fujimoto et al., 2013). Circular muscular fibers are located near the fundus and surrounding the body as it reaches the cervix (Fujimoto et al., 2013). These muscular layers of the uterus are essential in all stages of childbirth, as they carry out the contractions which push the fetus downward, thin and widen the cervix, expel the fetus, and drive delivery of the placenta.

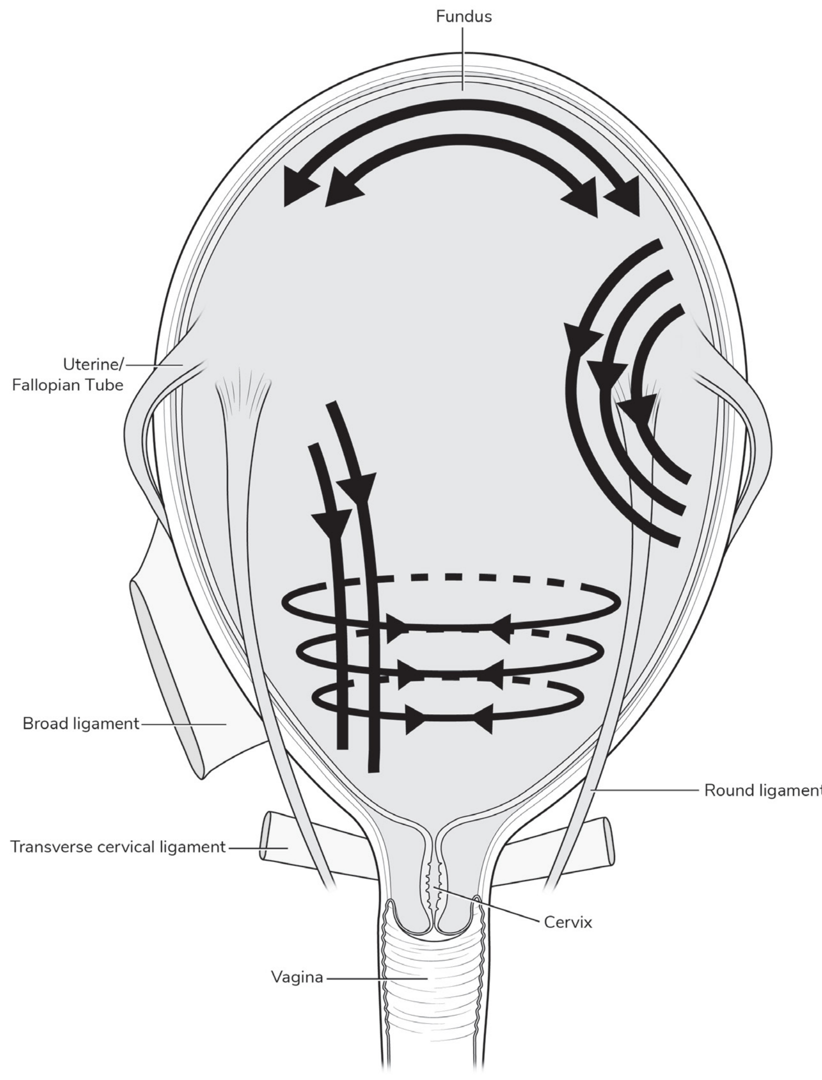

Figure 2. *Anterior view of a gravid uterus with arrows indicating example muscle fiber orientations within the myometrium, based on the findings of Fujimoto et al. (2013). The uterine fundus contains both longitudinal fibers and circular fibers originating near the uterine tubes and radiating towards the midline. The body of the cervix also contains both longitudinal and circular fibers that extend down to the cervix. The round ligament is attached at the anterosuperior portion of the uterine body, attaching distally to the mons pubis, pulling the fundus of the uterus inferiorly and slightly posteriorly during the late stages of pregnancy.*

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The initiation of uterine contraction is still a prime area of research, as many studies have found evidence of multiple pacemakers within the myometrium (Young, 2018). Coordination of uterine contractions is potentially a response to intrauterine pressures, which increase as the fetus grows, as well as mechanotransduction (Young, 2018). During the cervical dilation stage, the muscular layer of the uterus must generate high intrauterine pressures without moving the uterine contents. Pressure is distributed across the cervix and the walls of the uterus (Figure 3A). While there is a lack of movement, the smooth muscle in the myometrium progressively increases pressure inside the uterus by its continual contractions. It is only during the second stage of labor, the expulsion phase, that movement of the fetus is initiated (Figure 3B).

During pregnancy and especially childbirth, the cervix undergoes one of the greatest changes of the female reproductive system. All of these changes are largely due to the reduction in connective tissue makeup, led by hormones, and the increased forces placed on the cervix by the fetal head (Fruscalzo et al., 2016; Timmons et al., 2010). The external and internal ostia, normally very small openings, need to allow for the passage of the entirety of the fetus. The ostia, eventually reaching approximately ten centimeters in diameter, must allow for significant remodeling in tissue makeup and strength. These changes in the cervix are divided into four overlapping phases termed softening, ripening, dilation, and postpartum repair (Word et al., 2007).

Softening is the initial decline in tensile strength of the cervix in the first trimester to prepare for childbirth. This is the slowest phase of preparation by the cervix (Timmons et al., 2010). Ripening occurs in the days immediately preceding parturition. This happens when progesterone levels are high, and estrogen levels are low. The changes in hormone levels create a lack of collagen cross-linking and an immense loss of connective tissue makeup and turnover, resulting in a significant downturn in cervical strength (Rechberger et al., 1988). Dilation occurs during the first stage of labor and results in the widening of the cervical ostia.

The first stage of childbirth, a combination of effacement plus dilation, can be further subdivided into phases. First is the latent phase, characterized by the uterus exerting small irregular contractions to begin softening and widening the

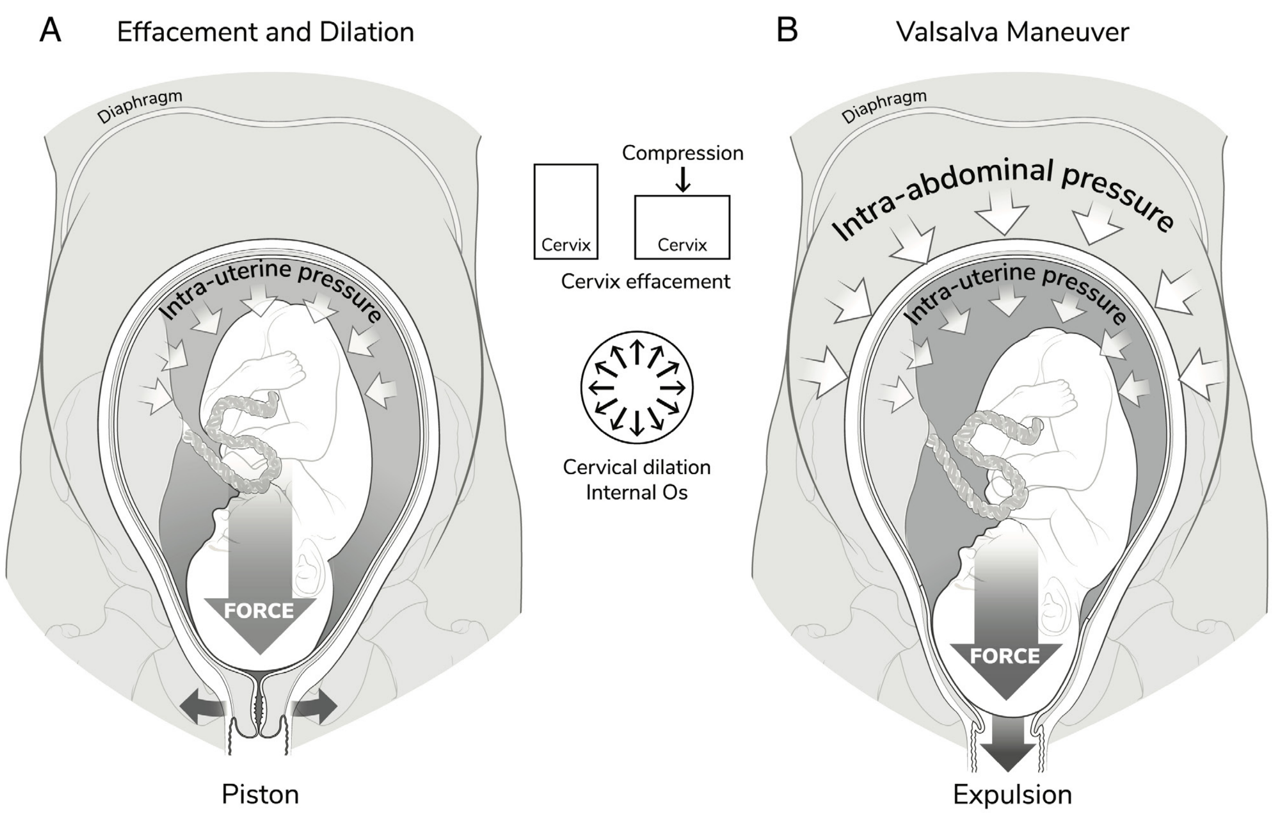

Figure 3. *A visualization of pressure and force during the active labor and expulsion stages of childbirth. A) Proper positioning of the fetal head on the cervix creates a piston-like seal, creating a compartment with incompressible contents. This seal allows muscle contractions to increase intra-uterine pressure and generate a downward force on the fetus that compresses the cervix resulting first in effacement and subsequent dilation of the internal os. B) Once cervical effacement and dilation are fully achieved, the expulsion stage begins. Increased intrabdominal pressure (Valsalva maneuver) combined with increased intrauterine pressure propel the fetus out through the cervix and vaginal canal.*

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cervix via contact with the fetal head (Figure 3A). The second is the active phase where the uterus contracts in a regular pattern to begin shortening the cervix. This step is called effacement. These contractions also allow for a widening of the ostia of the cervix, which is termed dilation. These openings widen between three and six centimeters during the active phase of effacement and dilation. The combination of these two phases completes the first stage of labor. At approximately ten centimeters in diameter, the cervix is fully effaced and fully dilated, providing a passageway for the fetus to the outside world (Cunningham et al., 2018).

With such a small opening to transmit a relatively large structure, how do the uterus and the cervix work together to achieve such an amazing feat? The key to successful childbirth relies on the concepts of force and pressure (Figure 3A). A force is an interaction that causes the movement or deformation of an object (Kerr & Rowe, 2019). During dilation and effacement, the object being moved, and changing its shape in response, is the cervix. Pressure is a force applied to an object divided by that object's cross-sectional area (Kerr & Rowe, 2019). Force has a direction and a magnitude, while pressure has only a magnitude and no direction. Rather, pressure can create a resultant force that has both direction and magnitude. In parturition, intrauterine pressure creates a resultant downward force exerted on the cervix by the fetal head. This force is a result of the release of pressure as the fetus is forced out of the uterus.

Intrauterine pressure is applied across the entirety of the internal uterine wall (Figure 3A). It has a magnitude, but as it is across the whole uterine wall, it does not have direction. Contractions of the uterus tighten the walls of the uterus and decrease the volume of the intrauterine space. Because the uterine contents are incompressible, this decrease in volume increases pressure. That pressure is best achieved by a fully enclosed space. To truly enclose the space, the fetal head must completely interact with the cervix (Grimm, 2016). Without proper interaction of the fetal head with the cervix, the intrauterine pressure is not able to increase properly with each contraction. This is a key issue when proper fetal positioning is not achieved, such as in breech-positioned babies. In a breech position, the feet of the fetus are pointed toward the cervix rather than the head. Unfortunately, the feet do not seal off the internal os as effectively as the head of the fetus would. The head creates the ideal seal on the cervix to aid in increased intrauterine pressure initiated by uterine and round ligament contractions. This seal creates a piston-like mechanism (Grimm, 2016). In a piston, there must be a tight seal, a chamber enclosed by that seal, and a crank shaft to apply pressure within the chamber. In a similar way, the fetal head acts as the seal on the cervix, the chamber is the inside of the uterus, and the structure applying pressure is the uterine muscular contractions. As the uterus contracts, the seal of the head remains fast on the cervix, creating an increase in pressure inside the uterus. The resultant downward force compresses the cervix, aiding in first effacement, or the shortening of the cervix, and then dilation of the internal os, widening of its opening (Figure 3A). This buildup of pressure is also key to expulsion of the fetus in the second stage of labor, described in the following section.

Incorporating biomechanics of the uterus and cervix in an anatomy lecture may look different depending on the student audience. For example, undergraduates may benefit from visualizing the muscle fiber directions within the myometrium as they think about uterine function and discuss layers of the uterus. When teaching about the anatomical relationship between the uterus and the cervix, it may be useful to discuss childbirth and the structural changes that the cervix must undergo to prepare for the expulsion of the fetus. For medical students, understanding the intrauterine pressure generation and interaction of the fetal head to create a piston-like downward force can be used to discuss why fetal position is important in the late stages of pregnancy.

Pressure Generation with Movement during Fetal Expulsion

The second stage of labor requires a combination of intrauterine and intrabdominal pressures to work collectively to expel the contents of the uterus through the cervical ostia, pelvic outlet, and vagina. As with the first stage of labor, there continues to be intrauterine pressure due to muscular contraction of the walls of the uterus. However, during the expulsion stage, pressure is also generated by maternal structures within the abdomen. Intrabdominal pressure is actively increased by the use of the Valsalva maneuver (Grimm, 2016). By employing this maneuver, the individual giving birth breathes in deeply, seals their airways, and forcefully attempts to breathe out. With the glottis closed, the air cannot escape, increasing thoracic pressure. As the pressure builds, a resultant downward force on the diaphragm increases pressure within the abdomen. This pressure increase in the thoracic and abdominal cavities adds additional downward force on the fetal structures within the uterus. The combined intrabdominal and intrauterine pressures greatly increase the downward resultant force on the fetus, which is funneled toward the pelvic floor (Figure 3B).

Pressure buildup within the abdomen and uterus from the Valsalva maneuver and contractions in the myometrium lead to a powerful downward resultant force on fetal structures, creating net movement of the fetus out of the uterus. This largely compressive (i.e. squeezing or compacting) force pushes the fetal head past the cervical ostia into the space created by the pelvic outlet and its surrounding soft tissue structures including the vaginal canal and surrounding pelvic floor muscles. As the head is forced through these relatively small spaces, it must allow for a certain amount of compliance to complete a successful and safe expulsion.

The fetal head undergoes significant pressure, compression, and deformation during childbirth (Yan et al., 2015). The ability

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to change shape is essential to accommodate the forces acting on the fetal head during parturition. The skull is made up of a collection of paired and unpaired bones (Tutschek et al., 2017). In an adult, the joining of these bones develops joints termed sutures; however, in the fetal skull, these sutures are not yet fused. In addition to these unfused sutures in the fetal skull, there are large, unossified areas, termed fontanelles, colloquially referred to as "soft spots" (Scheuer & Black, 2000). Fontanelles and the lack of fused joints allow individual bones to move to a small degree, permitting passage through the comparatively small opening of the cervix and vaginal canal. This compliance is key to fetal survival as the head moves past the relatively immobile bony features of the maternal pelvic outlet and the tight quarters of the vaginal canal.

The fetal structure must navigate a complex set of physical conditions as it is forced out. The maximal stress occurs on the fetal skull at the moment of fetal crowning due to resistance from the sum of the pelvic floor muscles and vaginal wall (Parente et al., 2010; Yan et al., 2015). As the fetal head is driven downward and out, the entirety of the fetal body must follow. After the skull passes through, one of the two shoulders will begin to interact with the cervix and take on the full resultant force of uterine contractions. As the uterus and its built-up pressure create compressive forces on the leading shoulder, it is forced out of the uterus.

However, compression is not the only force at play. While the shoulder passes through the vaginal canal it must undergo a significant amount of shear force (Grimm, 2016). Shear force is created by two opposing forces acting on an object in parallel. In this instance, the pubic symphysis can apply shear force onto the leading shoulder as it attempts to pass beyond the pelvic outlet. The pubic symphysis in this scenario is an immovable force acting in opposition to the inferior movement of the fetal shoulder due to intrauterine pressure (Draycott et al., 2008). Therefore, when a shear force is applied to the shoulder, the shoulder can be either moved or deformed. In instances where the shoulder takes on a significant amount of this shear force without intervention, the brachial plexus passing within the leading shoulder can be damaged (Dajani & Magann, 2014; Draycott et al., 2008; Grimm, 2016). To avoid damage to this region, the shoulder must shift naturally past the bony pelvis via external rotation (Grimm, 2021). If this does not occur naturally, the healthcare provider may need to intervene to turn the shoulder to bypass these immovable barriers (Grimm et al., 2010). Finally, as the shoulders emerge safely beyond the immovable bony maternal structures, the baby can be pulled free after its arduous journey.

Reproductive anatomy does not need to be the only place where this information is useful. For example, we recommend potentially incorporating discussions of the Valsalva maneuver into respiration lectures to drive home the relationship between pressure changes in the thorax and abdomen, perhaps utilizing Figure 3B. Additionally the forces involved in childbirth can be highlighted when discussing clinical complications for the fetus, as well as skull anatomy. Ideally, when teaching the female reproductive system, anatomy educators can describe the steps of childbirth as a sequence, describing how each anatomical structure relates to the biomechanical movements of parturition as a process**.**

Concluding Remarks

Anatomy is often seen as a difficult subject in a student's academic career. Much of the challenge is a result of learning new terminology and structures that are difficult to view and understand spatially (Kramer & Soley, 2002; Hall et al., 2018). Relating anatomical structures to their function may help students apply and retain the new material. The female pelvis and reproductive system are particularly challenging to students (Wilhelmsson, 2009). Connecting anatomy to parturition may make it easier to remember since the students are able to attribute each structure to a specific function to achieve one overall outcome. This exploration of parturition is one of many ways anatomy educators can integrate biomechanical concepts into their anatomy lectures to help students apply and appreciate the structures and functions of common anatomical features. This article is meant to supply the information and tools for anatomists to confidently teach about force and pressure as they relate to structures within and around the female pelvis during childbirth. Anatomy educators can explain the structure of the uterine layers or the ligaments of the female pelvis considering their role in the parturition process, giving students context for their anatomy knowledge. Further, this is a call for anatomists across institutions to continue to create and share additional biomechanical resources in their area of expertise that can be added to the teaching anatomist's repertoire.

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PERSPECTIVES ON TEACHING

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Undergraduate Nursing Students' Perspectives on Learning with 3D Virtual Cadavers in Pathophysiology Education

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Abstract

Anatomy, physiology, and pathophysiology are essential foundational concepts of nursing education. Despite consensus on the importance of the bioscience curriculum, teaching and learning challenges persist without widely recognized strategies to address the obstacles. 3D virtual cadavers are a promising technological resource to improve bioscience learning outcomes. Virtual cadavers (VC) are high-resolution images and simulations created from actual human cadavers that facilitate visualization and interactive learning opportunities. This study examined undergraduate nursing students' perceptions and experiences via electronic survey after participating in four VC lessons in their undergraduate nursing pathophysiology course. The feedback was overwhelmingly positive, with 100% of students and 90% of respondents, respectively, finding virtual cadavers helpful for their anatomy and physiology learning and for pathophysiology concepts. The students also reported that classes incorporating the virtual cadaver were enjoyable and increased their curiosity about the human body and diseases. They supported taking another nursing or science course incorporating virtual cadavers. Nearly all respondents recommended virtual cadaver technology be used as a learning tool for other students. Students' open-ended responses revealed common themes that highlighted the benefits of virtual cadaver lessons, particularly an ability to enhance visualization and facilitate connections across body systems. The results support expanding the adoption and research of technology-enhanced learning tools like virtual cadavers in nursing and biological science education. https://doi.org/10.21692/haps.2025.005

Key words: technology-based learning, nursing education, pathophysiology, 3D virtual cadaver, Anatomage Table

Introduction

Nurses who understand anatomy and physiology (A&P) and pathophysiology provide superior patient care, demonstrated by improved comprehension of nursing treatment rationales, enhanced communication across professional disciplines, and an increased ability to create trusting nurse-patient relationships (Colsh et al., 2021; Horiuchi-Hirose et al., 2023). Both student and practicing nurses recognize the importance of A&P education; however, they express challenges in integrating these concepts into clinical education and patient care. A&P content has decreased in the nursing curriculum since the 1980s, followed by criticism over pedagogical practices teaching these rigorous concepts. Educational frameworks have emerged from this problem. However, these frameworks favor discussions regarding the content versus teaching methodology and learning outcomes (Manchester & Roberts, 2024). Authors Bianchi et al. (2020) and Narnaware & Neumeier (2020, 2021) describe a similar phenomenon, a "bioscience problem," in which a lack of knowledge and retention of biosciences impairs academic and professional success in the nursing and healthcare professions.

Teaching and learning barriers of bioscience in nursing education include heavy science content courses all within the first year of the curriculum, a decreasing number of

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required credit hours, science and nursing faculty shortage, varying student preparedness and readiness, challenges in visualizing concepts, heavy memorization testing, limitations of online learning, and student anxiety (Satoh et al., 2023). Unsurprisingly, the bioscience curriculum has the highest nursing student attrition, contributing to a lack of diversity and the nursing shortage in healthcare (Bennet et al., 2021). These findings demonstrate an urgent need for innovative and effective instructional modalities to enhance learner success.

Cadaver dissection is the "gold standard" for anatomy instruction in medical education. However, it is rarely used in nursing education, which has led to limited literature supporting the learning benefits of cadaver education in the undergraduate student nursing population and the effects that this lack of experience can have on nurses' academic success (Capps et al., 2024). There has been an emergence of recent support for incorporating human cadavers (HC) into nursing education. One study evaluated 223 pre-licensure nursing students' perceptions using HCs, which included reports of quality learning experiences, high satisfaction, positive experiences and attitudes toward learning, and identification with the professional nursing role (Asman et al., 2022).

Another study evaluated the benefits of a combined HC with virtual cadaver (VC) technology in a health assessment nurse practitioner (NP) course, typically one of the first courses of NP education. Of the 17 NP student cohort, no students had previous HC or VC cadaver experience, and the cohort was an average of nine years from their last anatomy course. The VC technology was the Sectra™ table, a 55-inch 3D virtual anatomy interactive table. Researchers evaluated pre- and post-self-confidence of pediatric anatomy knowledge within significant body systems. Confidence statistically improved in all systems except head, eyes, ear, neck, and throat (HEENT). Qualitative responses expressed benefits to learning through more profound understanding, visualization ability, and interactivity (Whited et al., 2019). The support for HC use and HC supplemented with VC support are insightful. However, HC use in nursing education is limited due to restraints such as cost, space, and high enrollment, making VC an appealing alternative. (Washmuth et al., 2021).

A commercially available 3D virtual cadaver technology tool is the Anatomage Table™ (Table). The Table utilizes high-resolution imaging techniques created from actual cadavers, constructing computer-based, immersive, and interactive learning activities and has become increasingly available in higher education (Raja et al., 2022). In addition to anatomical images, the technology includes other features, such as functional anatomy that involves simulations of physiologic functions, a large inventory of diagnostic images (CT, MRI), 3D renderings, and histology slides. This expanding application into diseases and clinical simulation creates opportunities beyond the A&P curriculum.

The literature on VCs in healthcare education echoes that of HCs. There is a significant amount of research on VC use in medical and other graduate education and very little on undergraduate nursing education (Raja et al., 2022; Kavvadia et al., 2023). Pertinent research supporting the use of VC in nursing education addresses their impact on learning in anatomy courses or graduate-level nursing programs. Though limited, reports about the learning advantages of VC technology in undergraduate nursing education are promising.

Bianchi et al. (2020) implemented VC into anatomy education for first-year nursing students and assessed anxiety levels, exam scores, and student perception. Key data results demonstrated increased self-confidence and decreased anxiety. Similarly, Narnaware and Neumeier (2021) evaluated student performance and perception utilizing VC in the anatomy curriculum in a population of undergraduate nursing students. Results demonstrated improved midterm and final exam scores, increased GPA, and positive experience, supporting VC as a valuable technology in undergraduate nursing anatomy education.

The American College of Nursing Education (AACN) requires pathophysiology as a core science competency in the baccalaureate nursing curriculum (2021). Although all nursing programs in the United States teach pathophysiology, pedagogical practices identifying the most effective methods for teaching pathophysiology are unclear (Colsh et al., 2021). Echoing the described bioscience problem, educators and students at the author's university express a lack of understanding and retention of A&P concepts as a significant barrier to student success in pathophysiology and upper-level nursing courses. VC learning was integrated into a nursing pathophysiology course to address this challenge. This study aimed to explore students' perspectives on their learning experiences utilizing VC technology.

Materials & Methods

3D Virtual Cadaver Technology

The 3D VC technology utilized for this study was the Anatomage Table™ (Table) purchased from Anatomage, Inc. (Santa Clara, California, USA).

Pathophysiology Course

The course in which we integrated the Table is a 200-level pathophysiology course taught in the nursing school, typically in the second academic year of the traditional undergraduate curriculum. An overall course grade of a C or higher must be earned in the required bioscience prerequisite courses: microbiology, two semesters of anatomy and physiology, and a combination chemistry/biology course. Pre-requisite courses are offered in the biology department and taught by the science faculty. The

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pathophysiology course learning objectives focus on medical physiology, etiology, pathology, and clinical manifestations of disease relevant to nursing clinical practice. This course's curriculum does not include treatment or care management concepts. Therefore, it remains a foundation for nursing science courses. The predominant pedagogical practice of the course consists of active learning facilitated by a "flipped classroom" structure, creating an appropriate classroom environment to implement VC learning.

Lesson Design and Implementation

A&P nursing courses at our institution do not include human or virtual cadaver learning. VC lessons for this study were designed with the expectation that students did not have prior cadaver education learning experience. The principles guiding Table learning design and implementation included: a) alignment with content objectives, b) selection of concepts that are challenging to visualize, c) integration of A&P relevant to pathophysiology disease processes, and d) opportunities to incorporate health assessment principles (a health assessment course is a co-requisite class during this nursing semester).

Students completed content-aligned assignments before the Table lessons. The classes with Table learning activities were held in the Hill-Rom Simulation Center at Marian University where the Table is located. The course has three sections with a maximum enrollment of 25 students per section. To facilitate appropriate numbers at the Table, students rotated through activity stations.

Throughout the 16-week semester, four learning lessons utilizing the Table were completed by students enrolled in this course. Three of the four lessons were faculty-led, involving a lecture style with some student interaction on the Table. Faculty-led lecture lessons included multiple Table functions, such as digitized cadaver visualization, blood flow simulation, histology, physiology simulations, and clinical imaging. Lecture-style lessons accommodated groups of 10-12 students at the table. The fourth and final lesson was completed as a collaborative student-led activity. In groups of 6-8, students worked in a cooperative group following a guide and worksheet. Lesson summaries are described below by semester week, and Figure 1 depicts representative images from the lessons.

Lesson 1 (Week 3): Students were introduced to the VC technology, Table cadavers, and how to use various functions. Concepts in this lesson included anatomy of the lymphatic and vascular systems and related A&P concepts including fluid body compartments, fluid movement, and metastasis.

Lesson 2 (Week 6): This lesson focused on the central nervous system, neurovascular A&P, and associated diseases. Concepts were applied to cerebral vascular accidents and spinal cord injuries, with comparisons of neurodiagnostic imaging (CT vs. MRI).

Lesson 3 (Week 9): The third lesson covered cardiac A&P, including electrophysiological conduction pathways. VC simulations utilized included myocardial infarction, cardiac catheterization, and arrhythmias.

Lesson 4 (Week 11): Anatomage Inc. includes the "Table Activities" curriculum, the standard A&P content in guides, and worksheets learners can follow at the Table. The fourth lesson implemented in the course was modified from the "Respiratory Diseases" Table Activity, and students followed the steps and answered questions on the worksheet. The content involved applying anatomical concepts of the respiratory system to pulse oximetry, chronic obstructive pulmonary diseases, pleural effusions, and pneumonia. Students navigated table functions including cadaver images, clinical case study images, and histology. Aside from the clinical imaging, students could navigate the Table with minimal support from faculty.

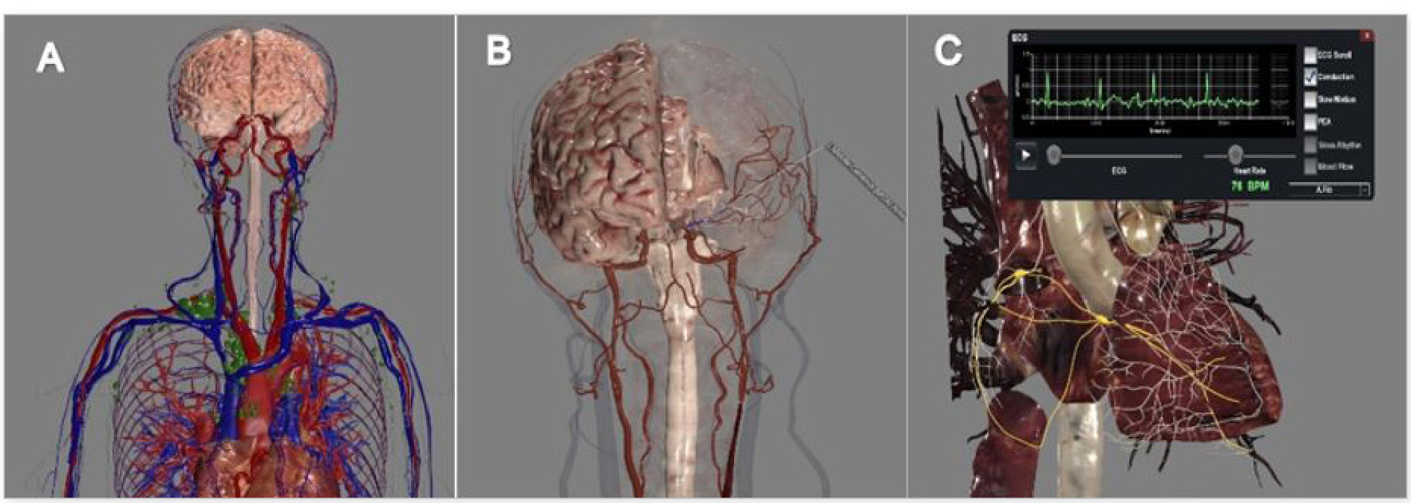

Figure 1. *Example images of concepts from the VC lessons: A) right-sided thoracic lymphadenopathy secondary to lung cancer, B) left middle cerebral artery ischemic infarction, and C) abnormal cardiac conduction pathway of atrial fibrillation. Images used with permission.*

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Survey instrument

A survey instrument was developed using Qualtricsä and distributed via an online learning management system after students had completed all four VC lessons. The questionnaire included seven 5-point Likert scale questions (Figure 2) and two open-ended questions about student learning perspectives. Participation in the survey was voluntary and anonymous.

Regulatory considerations

The Marian University Institutional Review Board approved this study as protocol S23.200.

Results

Of the 55 undergraduate nursing students enrolled in the pathophysiology course, 25 completed the survey with a response rate of 45.5%. Figure 2 provides survey responses by percentage. Students unanimously reported that the Table was helpful for their learning of A&P (100%, 25/25), with 64% (16/25) indicating strong agreement. Similarly, more than 90% of respondents (23/25) reported that the Table was helpful for their learning of pathophysiology, with 20% (5/25) indicating strong agreement. Respondents reported that learning experiences at the table were enjoyable (88%, 22/25) and increased their curiosity about the human body and diseases (88%, 22/25). Respondents supported taking another nursing or science course incorporating the Table (88%, 22/25), with the majority (52%, 13/25) indicating strong agreement. Notably, 76% of respondents (19/25) showed that, with some direction, they would be confident in their ability to explore and learn at the Table without a faculty member present. Overall, nearly all respondents (96%, 24/25) agreed with the statement, "I would recommend the [Anatomage Table] as a learning tool to other undergraduate nursing students." Student disagreement was present in two of the seven questions: 4% (1/25) somewhat disagreed that the Anatomage Table helped them learn pathophysiology, and 8% (2/25) strongly disagreed that they would be confident utilizing the Table without faculty present.

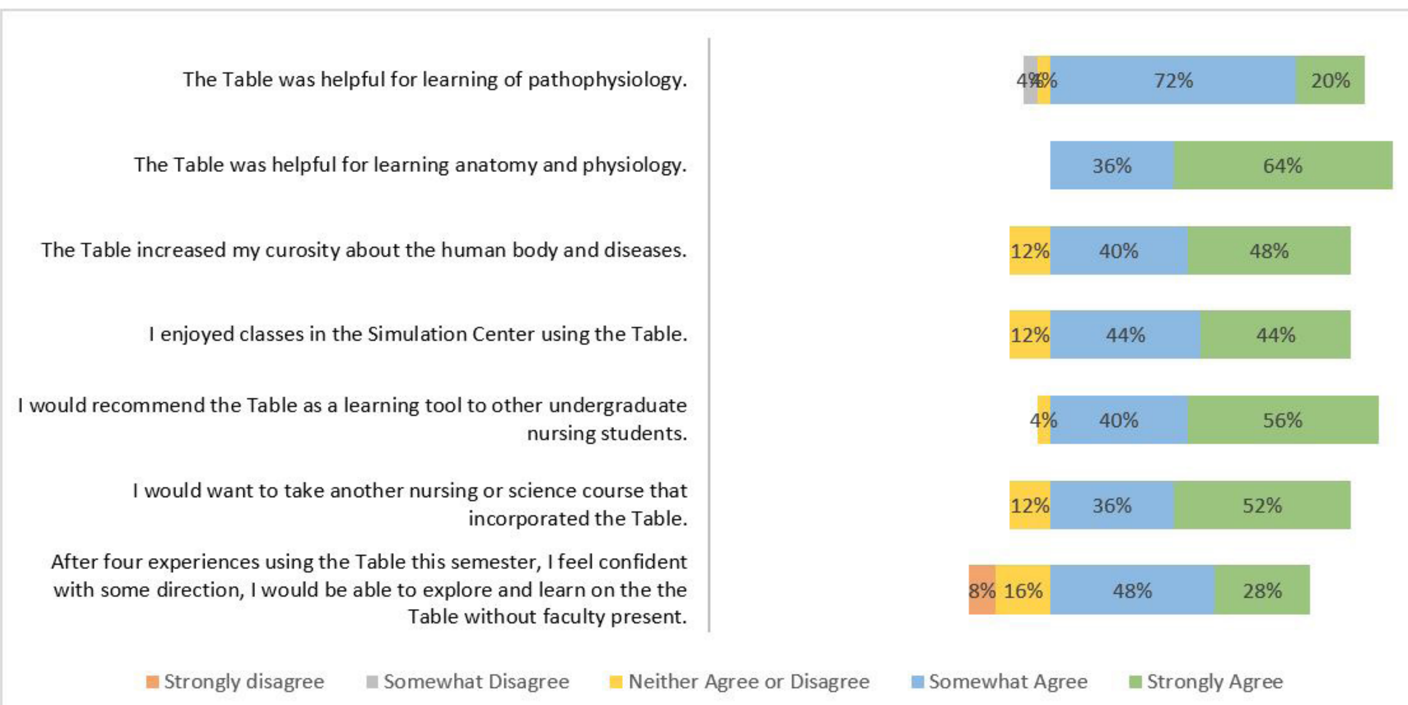

Figure 2. *Survey feedback by percentage regarding learning experiences with VC. (n=25)*

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Discussion

Our findings support VCs as a practical learning resource to improve learning outcomes of bioscience concepts in nursing education. Previous studies that evaluated the nursing population demonstrated benefits of VCs specific to the anatomy curriculum (Bianchi et al., 2020; Narnaware & Neumeier, 2021). The student feedback collected in this study reported benefits to pathophysiology learning and recommendations for future courses that support VC use outside of first-year A&P courses. In addition to the benefit of learning content, students reported enjoyable experiences that fostered curiosity about disease and the human body and communicated yearning for increased access to this technology. These positive experiences endorse VC use in nursing education and highlight the need for more student opportunities to use this technology.

While learning experiences were predominantly positive, the most significant proportion of negative student responses pertained to the student's confidence in operating the Table independently. Interestingly, despite this reported lack of confidence, students' recommendations on the open-ended question included preferences to use the Table in smaller groups or as individuals. This recommendation is logical, given the interactive features of VC. However, to effectively facilitate smaller group sizes or individual student learning, these activities would need to include outside classroom activities such as student-accessible access time or peer learning opportunities (tutoring, supplemental instruction), and assignments to which students had access. Providing faculty support at the Table is challenging for this type of Table use, and it would be necessary to address the reported lack of student confidence barrier. Strategies for increasing confidence could be introducing the Table earlier in the curriculum during A&P courses, which aligns with students' recommendation to utilize this technology in the preceding courses to pathophysiology.

Limitations

During the study, VC lessons were designed mainly to feature anatomy-based concepts that could apply to pathophysiology course objectives. Since the study's completion, our institutional proficiency has increased and diversified on VC applications. Software updates from Anatomage, Inc. have expanded applications pertinent to clinical care education; examples include increased physiology simulations, more diagnostic imaging, and procedure simulations. These advancements in functionality offer more opportunities for research in clinical education that we did not capture in this study.

Conclusion

3D virtual cadaver technology is a valuable resource for bioscience and nursing education. While the tool benefits A&P, the positive student feedback for pathophysiology learning and student recommendation for continued use in nursing education coupled with the growing clinical functions of the Table are promising that incorporating VC use into upper-level nursing courses and clinical education could improve the theory-practice gap of bioscience. The nursing students expressed a desire to increase VC use within the curriculum. To do this effectively, future research should focus on developing and evaluating specific teaching and learning methods with VC. Additionally, the practicality of utilizing the technology efficiently will be creating strategies that facilitate students' access, ability, and confidence in operating VC technology. Overall, our findings emphasize the potential of VC in innovating nursing education and call for continued research and implementation.

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PERSPECTIVES ON TEACHING

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HAPS Curriculum & Instruction 2022 Laboratory Survey: Teaching Anatomy and Physiology during the COVID-19 Pandemic

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Abstract

In this third and final manuscript from the Human Anatomy and Physiology Society (HAPS) 2022 Lab Survey we document the efforts of Human Anatomy and Physiology (A&P) educators in response to the COVID-19 global pandemic. Institutional, instructional, and student demographics, and laboratory activities and learning outcomes were the focus of the first and second manuscripts, respectively, in this series. Sixteen new questions for the third part of the survey asked about changes in instructional resources and funding, safety procedures, and effects on course policies for the partial academic year of March through May 2020 and the 2020-2021 and 2021-2022 academic years. Institutional mandate or instructor choice rather than government mandate determined course format (in-person, online, or hybrid) across the three time periods. Instructor-created videos, face masks, and temporarily shifting the class online were the most common resource, safety procedure, and response to disruptions, respectively. Online lab practicals were frequently used for assessment during the pandemic, with a lockdown internet browser or honor system the most frequently used methods for proctoring. Perceived course rigor and learning outcomes assessed did not differ appreciably during the time periods in question, while the variety of testing and assessment methods increased. Although respondents indicated an expected increase in variety of course format once the pandemic was over, this expectation is not statistically significant. While there were many positive effects of the pandemic, including increased compassion for the stressors affecting students, respondents did not indicate feeling more invigorated in their teaching. https://doi.org/10.21692/haps.2025.006

Key words: anatomy & physiology, education, survey, lecture, laboratory, online, remote, COVID-19, pandemic

Introduction

HAPS Lab Survey Background

In 2022, a subcommittee of the Human Anatomy and Physiology Society (HAPS) Curriculum and Instruction (C&I) Committee delivered a survey to educators. The 2022 survey was the third iteration of the HAPS Lab Survey, previously distributed in 2014 (Brashinger, 2014) and 2017 (Brashinger, 2017), and it initially focused solely on revising and expanding questions on demographics (Britson et al., 2023a) and laboratory activities and learning outcomes (Britson et al., 2023b). The global COVID-19 pandemic, however, disrupted the scheduled release of the survey in 2020. Subcommittee members quickly recognized the

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opportunity to assess how a sample of educators was forced to think and work differently because of the pandemic, by linking responses to new questions with those from the first (demographics) and second (lab activities and learning outcomes) group of questions. This third and final article in the 2022 HAPS Lab Survey series documents how we, as educators, strove to meet the educational needs of our students during this unprecedented time in higher education. We begin with a review of distance learning and the benefits and challenges unique to human anatomy and physiology (A&P) education.

Background and Benefits Associated with Remote Learning

Online and/or remote education is not a new phenomenon (Baum & McPherson, 2019; Means et al., 2010), and had been expanding through the use of online learning management systems (e.g., Canvas, Blackboard, Moodle, etc.), digital and online resources from major publishers (e.g., *Mastering* from Pearson, *Connect* from McGraw-Hill, and *Evolve* from Elsevier), and other resource providers well before the imposition of the COVID-19 pandemic. Yet, in the face of institutional pivots in education formats and other public health restrictions due to the COVID-19 outbreak, the use of online educational resources quickly expanded in response to the need to continue educating while following restrictions on public gatherings (Davis & Pinedo, 2021; Ghosh, 2022; Harmon et al., 2021).

It is important to differentiate between courses being online and those that are remote (Baum & McPherson, 2019; Davis & Pinedo, 2021; Ghosh, 2022; Harmon et al., 2021; Means et al., 2010; Pollock, 2022). Both online and remote education should be seen as any means to deliver content and instruction outside the actual physical campus of the institution. By incorporating a variety of technology and multimedia modalities, their difference lies in the necessity and requirement for students to access the course through an internet platform (online) or not (remote) (Baum & McPherson, 2019). Additionally, we must delineate between instruction based on primacy of interaction and content acquisition to be either synchronous (established time for meeting online) or asynchronous (self-paced) regardless of the use of learning modules in the structure of the course (Baum & McPherson, 2019; Chang et al., 2022; Means et al., 2010). Course format can further be differentiated into instruction defined as hybrid (occasionally referred to as blended) based on the requirement to have portions of the class meeting time during the semester consisting of face-to-face sessions (Liachovitzky & Wolf, 2019; Singh et al., 2021). For most science courses, such as A&P, the distinction between the in-person versus online/remote or hybrid course format is typically defined by the location in which students are expected to complete the laboratory component of the course.

There is a general impression that traditional face-to-face instruction offers a superior educational experience (Davis & Pinedo, 2021; Ghosh, 2022; Liachovitzky & Wolf, 2019; Pollock, 2022). However, online and remote education offer unique benefits to the institution, educator, and students particularly when viewed in combination with the means of delivery (i.e., synchronous, asynchronous) that allows increased connections between stakeholders (i.e., institutions and governing boards, educators, and students) of diverse backgrounds (Baum & McPherson, 2019; Chang et al., 2022; Ghosh, 2022; Means et al., 2010; Ostrin & Dushenkov, 2016; Pollock, 2022; Singh et al., 2021; Zhang et al., 2021). Online/remote education also provides institutions with the ability to reach a student population that it would not otherwise have access to, and to offer courses that it may not have the ability to offer in a traditional format.

For educators, the opportunity to reach and interact with students across the breadth of possible modalities and technologies that make content available in the online or remote format must be balanced with the personal costs of converting from one instructional mode (e.g., in-person) to another, unfamiliar mode (e.g., online) and institutional costs of maintaining course consistency across formats. A faculty member without previous online teaching experience would need training on how to extrapolate pedagogy from the traditional classroom setting to an online setting as well as the use of different electronic resources and software. Increased pressure to engage students who are learning remotely might require the development of new skills and pedagogy.

For students, online learning offers many benefits such as availability and flexibility in both time and location. Flexibility may allow students to self-pace through the course content, leading to a greater chance of ensuring their ability to master materials being taught. A study involving 198 students and their perspectives regarding online teaching found that many students consider online learning to require a higher level of individual accountability and independent learning (Sit et al., 2005). However, decreased opportunities for human interaction, which is integral for establishing peer relationships, and in-depth subject-matter discussions are some of the hindrances to online learning (Sit et al., 2005). How well these benefits transmit to student learning and successfully meeting course goals and learning outcomes is dependent upon minimizing the challenges and drawbacks for students, educators, and institutions (Baum & McPherson, 2019; Chang et al., 2022; Davis & Pinedo, 2021; Pollock, 2022; Zhang et al., 2021).

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Challenges Associated with Remote Learning

For instructors, a significant concern pertaining to online or remote education is maintaining the integrity, reliability and design of assessments used, and the effectiveness of exam proctoring approaches (Albalushi et al., 2022; Özen et al., 2022a; Pather et al., 2020; Sadeesh et al., 2021; Singal et al., 2021; Walsh, 2015). The potential for student collusion, screenshotting and distributing exam or quiz questions, and accessing prohibited course resources are legitimate concerns that can erode the validity of these assessments. Various proctoring services mitigate the decline of assessment reliability; however, they may also introduce student privacy issues (Albalushi et al., 2022) and racial bias against people of color leading to increased flagging for potential cheating (Yoder-Himes et al., 2022). Furthermore, online assessments can be time-consuming and difficult to compare with in-person instruction (Albalushi et al., 2022; Rastgoo & Namvar, 2010). Student feedback also indicated a preference for conventional assessments (e.g., in-person and paper exams) over those administered online, as reported in a study of anatomy students by Sadeesh et al. (2021).

Remote lab instruction may also limit the number and variety of activities offered and poses the challenge of how to teach and develop proficiency in manipulative skills, such as dissection (Stone et al., 2022), and humanist aspects, such as empathy and compassion (Longhurst et al., 2020; Parker & Randall, 2021). A significant difficulty of online or remote A&P instruction is how to convert three-dimensional lab structures from a donor, organ specimen from a donor or livestock animal (e.g., a sheep brain), or model to accurate two-dimensional screen images (Longhurst et al., 2020; Sadeesh et al., 2021; Stone et al., 2022). Importantly, anatomical donor-based anatomy instruction has been revealed to enhance student comprehension of three-dimensional relationships within the human body and confers recognition of variations and pathologies associated with anatomy (Longhurst et al., 2020). Singal et al. (2021) also reported that a clear majority of anatomy students surveyed acknowledged that dissections helped their comprehension of this subject more readily.

For students, the absence of the "hands-on" aspect of instruction and physical access to lab specimens (e.g., manipulating a bone, measuring a physiological response or performing a dissection) and models may create limitations to understanding (Schaefer, 2022; Singal et al., 2021). Lost dissection time may negatively impact students' confidence in anatomy, with students considering not having access to anatomical donor materials to be detrimental to their progress (Stone et al., 2022). Brown and Peterson (2021) discussed the efficacy of kinesthetic learning for developing anatomical structure knowledge, while Van Nuland and Rogers (2017) have described how handling a skeleton increased anatomy learning compared with virtual tools.

Student engagement, which links to a sense of belonging and motivation, may also be negatively affected by online learning (Britson 2022; Ghosal et al., 2021; Longhurst et al., 2020; Mossa et al., 2023; Singal et al., 2021).

Another shortcoming of online or remote education is the reduced student interaction with both faculty and peers (Brockman et al., 2020; Dulohery et al., 2021; Özen et al., 2022b) which complicates mentoring of student progress (Mossa et al., 2023). Meeting the student or institutional expectation of continuous access to instructors poses another challenge for those teaching remotely (Pather et al., 2020). The challenge of successfully managing and supporting all students (Canninzzo et al., 2019), particularly those with learning challenges or emotional health issues (Pather et al., 2020), is also complicated by distance learning.

Inherent with online learning is the need to ensure all students have equal internet connectivity (e.g., access equity), along with the requisite computer and instructional technologies. Unequal access to these resources comprises a potential barrier for online education (Pather et al., 2020; Schaefer, 2020; Singal et al., 2021) and can raise genuine equity issues for disadvantaged student populations, including those living in rural or remote areas (Albalushi et al., 2022; Pather et al., 2020). A compounding factor for many health science students, especially those in their first or second academic years, is their struggle with time management, self-motivation and self-discipline to complete assigned work while minimizing distractions. These struggles can be amplified by online instruction (Broadbent & Poon, 2015) further diminishing the likelihood of students successfully completing online or remote coursework (Castillo-Merino & Serradell-Lopez, 2014; Pather et al., 2020; Singal et al., 2020).

For institutions, providing adequate instructor training, available technology and software, and academic support for all members of an instructional team (e.g., teaching assistants, tutors, peer leaders, etc.) for successful online instruction requires a considerable investment of time and resources (Pather et al., 2020; Walsh, 2015). Additionally, acquiring consent and providing secure platforms for sharing and displaying anatomical donor images online, with their commensurate ethical and legal limitations, constitute a specific challenge for online or remote anatomy education (HTA Human Tissue Authority, 2020; Longhurst et al., 2020; Pather et al., 2020).

Another challenge facing institutions and accrediting organizations is achieving alignment of online learning objectives/activities with accrediting body standards and benchmarks for anatomy coursework, consistency across multiple instructors at a single institution, use of scientific instrumentation, and assessment (Biggs and Tang, 2011;

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Longurst et al., 2020; Pather et al., 2020). Inherent in these standards is the disciplinary requirement of a three-dimensional comprehension of structural relationships between body structures (Longhurst et al., 2020; Sadeesh et al., 2021), an understanding which is effectively learned with anatomical donor-based instruction and dissection (Estai and Bunt, 2016; Flack and Nicholson, 2018; Pather et al., 2020). As noted previously, however, anatomical donors may be of limited applicability within a remote learning environment. Considering this issue, Longhurst et al. (2020) and others have expressed concern for a potential loss of curricular alignment when transitioning from in-person to online instruction and assessment. Recommended strategies to mitigate this concern include evaluating competencies to address perceived gaps in learner knowledge (Pather et al., 2020), determining what these gaps may be (Wilson et al., 2019) and carefully selecting digital images that have a clear orientation (Longhurst et al., 2020; Meyer et al., 2016).

The Response of HAPS to the COVID-19 Pandemic

In mid-March of 2020, most educational institutions in the United States made the decision to be fully online for the remainder of the academic year with the goal of preserving human health and minimizing the strain on healthcare providers. Educators were given approximately one week to transform their courses from an in-person to a fully online format, while being mindful of the benefits and challenges that the online format creates. From March to May 2020, there were many asynchronous online discussions on the HAPS listserv where members were sharing resources like YouTube videos they produced, histology websites, and animations. The need for continued online learning during the 2020-2021 academic year coincided with the end of Adobe Flash animation in December 2020 (Fox, 2020) meaning that many online resources used earlier in 2020 (e.g., immersive web sites with video and animation plug-ins) would no longer be functional. Many A&P instructors had to start fresh, again, in preparation for the fall 2020 term and needed advice on what works best for A&P students learning remotely, online, or in a hybrid format.

During the summer months of 2020 (June through August), the HAPS C&I committee, chaired at that time by Rachel Hopp, created a subcommittee on online learning and used the HAPS listserv to recruit veteran online A&P instructors to lead a webinar (a HAPS Town Hall meeting) focused solely on teaching A&P online or via remote learning. On 7 July 2020, over 200 participants engaged with the presentation team of Rachel Hopp, Marni Chapman, Margaret Weck, Cheryl Hill, Heather Armbruster, Kevin Patton, Steven Sullivan, Michael Kolitsky, and Tom Lehman on the topic of *Just Keep Teaching: How Can I Teach a High-Quality A&P Lab Fully Online?* This town hall had three breakout sessions: Anatomy online, Physiology online and Remote A&P (i.e. at-home resource-based activities and labs using supplies from your kitchen and/or local drug store). Over 100 participants also learned from this team during a town hall on 2 December 2020 (*Online A&P Labs Town Hall - Focus on the Respiratory System*).

The HAPS C&I Lab Survey Sub-committee had the following goals in this third and final component of the survey: (1) document how the COVID-19 pandemic influenced changes in instruction across a wide range of individuals, institutions, and A&P-related courses; (2) compare responses across geographic regions and type of institution; and (3) provide guidance in developing a baseline for the future development of best practices in online teaching. Meeting these goals will support individual educators in their evaluation of what works for them in comparison to what a wide variety of educators have used.

Materials and Methods

The third part of the HAPS 2022 lab survey contained 16 questions that focused on how A&P educators, and education, were affected by the COVID-19 pandemic. The 2022 HAPS lab survey obtained Institutional Review Board EXEMPT status under 45 CFR 46.101(b)(#2) by The University of Mississippi's Institutional Review Board (IRB, Protocol #22x-129) in January 2022, and was open for responses from February to August 2022, with the primary period of volunteer respondent recruitment occurring during February, March, and May (Britson et al. 2023a). Since responses from part 3 of the 2022 lab survey are linked to parts 1 (demographics; Britson et al. 2023a) and 2 (activities and learning outcomes; Britson et al. 2023b) by respondent, we are able to compare responses about lab activities and learning outcomes to demographic data. Full details of survey development and revisions are presented in Britson et al. (2023a).

Quantitative questions focused on four areas. First, respondents were asked about their changes to course resources and how changes were implemented or funded. Second, implementation of safety procedures as well as response to pandemic-related disruptions were quantified. Third, effects on course policies, assessment procedures, and performance standards were examined. Lastly, changing institutional expectations and educator outcomes were asked of respondents. The COVID-19 time period was divided into the partial academic year of March to August 2020, the 2020-2021 academic year, and the 2021-2022 academic year. There were two free-response questions about topics that were (or were not) moved online and why, and what course and educator changes may become permanent as a result of the pandemic. Frequency data and descriptive statistics were calculated for all quantitative survey questions. All statistical tests (e.g., t-tests, ANOVAs) were conducted using SPSSV29 software licensed to the University of Mississippi.

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Results

A total of 176 survey responses were submitted (Britson et al., 2023a). Across the partial academic year of March to August 2020, the 2020-2021 academic year, and the 2021-2022 academic year, the predominant laboratory instruction format shifted from 100% online (asynchronous or synchronous) towards hybrid or in-person by choice or institutional mandate (Fig. 1). Only 1 respondent indicated that they taught laboratories in person due to a governmental mandate during the partial academic year of March to August 2020, and this response was removed from further statistical analyses. For the 2020-2021 and 2021-2022 academic years, there were not enough degrees of freedom to perform statistical tests for differences due to governmental mandates by a governmental entity (e.g., US State or Canadian Province) to teach in-person. A one-way analysis of variance (ANOVA) test for ranks (i.e., Kruskal-Wallis test) was performed on the ordinal response data to test for differences across HAPS regions (Human Anatomy & Physiology Society, 2023a). There were no differences in the number of responses indicating that laboratory instruction was in-person by governmental mandate across the four HAPS regions for both the 2020-2021 [$H(3, n = 1) = 0.000$ (adjusted for ties), $p = 1.000$] where responses to this question were only from the Central and Southern regions and 2021-2022 academic years [$H(8, n = 3) = 0.000$ (adjusted for ties), $p = 1.000$] where responses were from all HAPS regions.

Instructor-created videos were the most common resource added to teach gross anatomy (56.7% of responses) and physiology (52.8% of responses) content during the pandemic (Fig. 2). Static, digital images (48.9%) and computer-based simulations (45.5%) were the next most frequently added resource for gross anatomy and physiology, respectively. Static, digital images (49.5%) and instructor-created videos (41.6%) were the most common resources added to teach histology content during the pandemic. Commercial or in-house lab kits were a less frequently added resource for teaching, and, when used, were primarily funded, in order of decreasing use, by lab fees, independent purchase, or Coronavirus Aid, Relief, and Economic Security (CARES) Act funds (Fig. 3) during each of the three time periods. Common themes to the free response question, "Is there anything you would like to tell us about topics you moved online or wished you could move online?" included a permanent preference to perform some activities online, an inability to find adequate online resources for some skill development activities, and a lack of transferability of online lab credits to professional programs (Table 1).

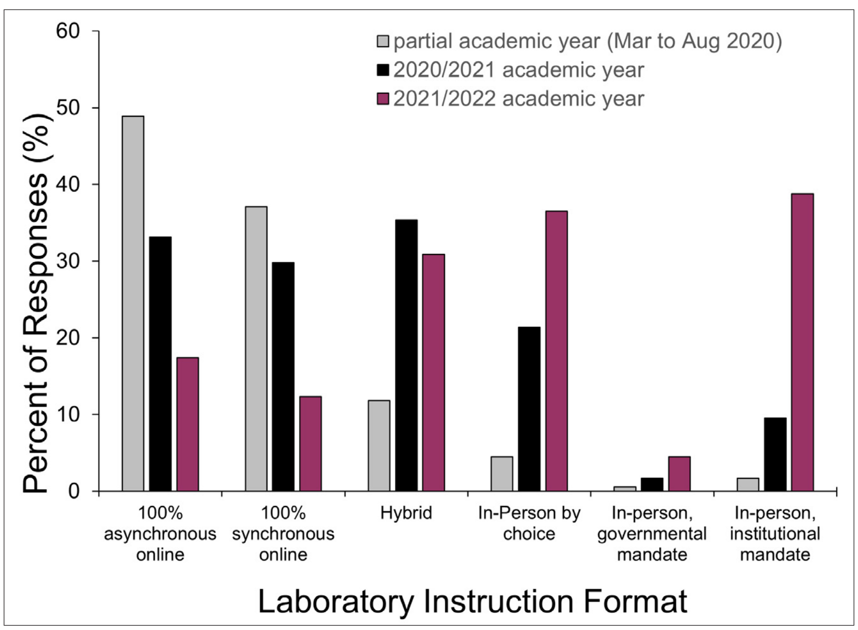

Figure 1. *Percent of survey responses (n=176) to the question, "During the following time frames of the COVID-19 pandemic, how were your institution's anatomy and physiology LABS taught? SELECT ALL THAT APPLY."*

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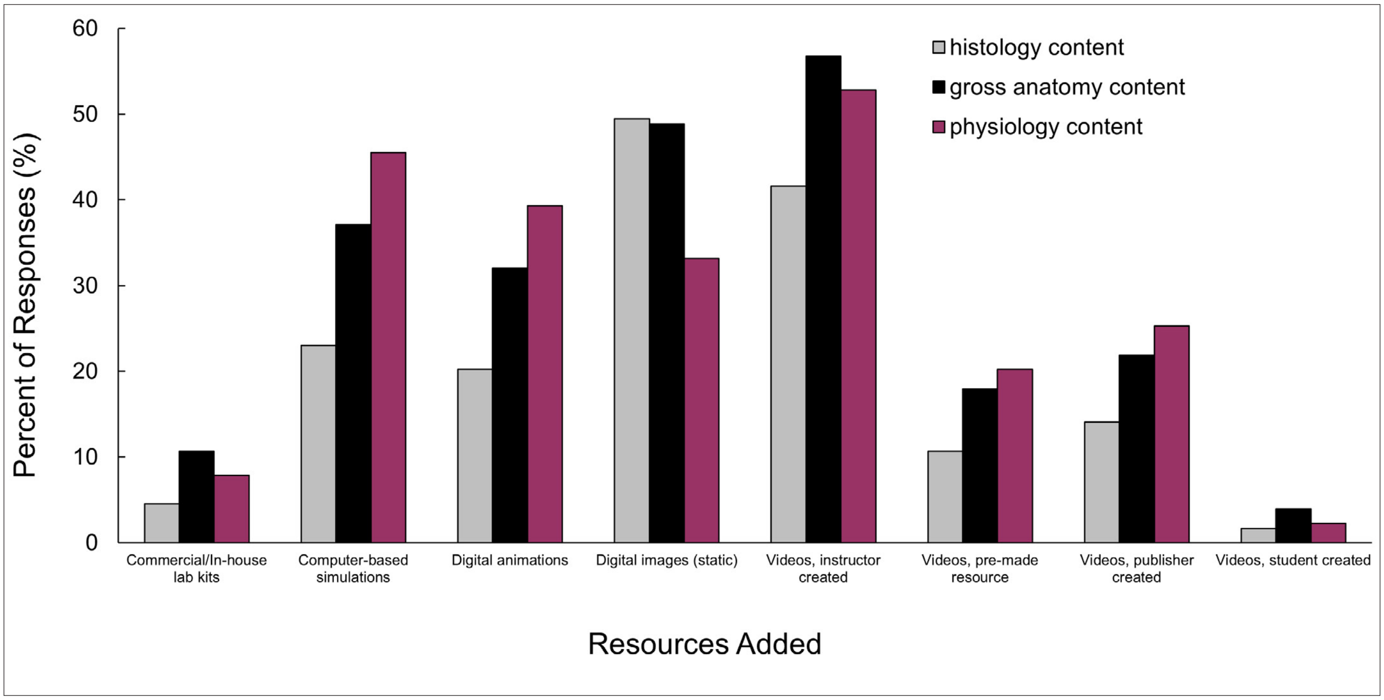

Figure 2. *Percent of survey responses (n=176) to the question, "In response to the COVID-19 pandemic, which of the following resources did you ADD to teach content? SELECT ALL THAT APPLY."*

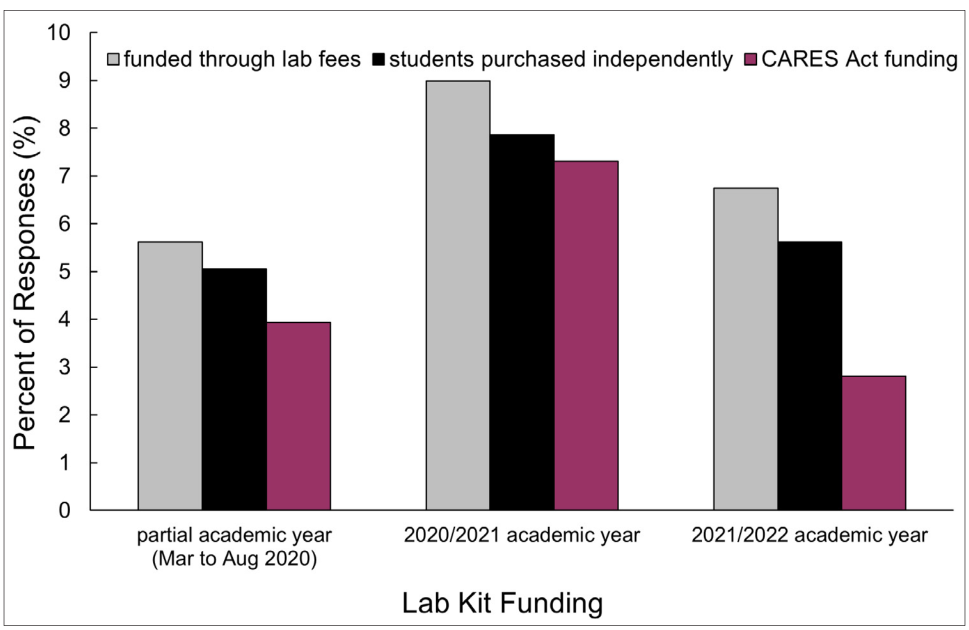

Figure 3. *Percent of survey responses (n=176) to the question, "If your students used 'lab-in-a-box' kits or equipment, how was the purchase (or rental) funded? SELECT ALL THAT APPLY."*

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Theme	Sample Response
Some online laboratory activities / software discovered during COVID continue to be used in onsite classes. (This includes recordings made by faculty & well-designed virtual experiments.)	'I have kept the enzyme lab online, because then it always works.' 'I moved immunity and lymphatics completely online because I did not have good labs for either of these topics.'
Faculty could not find adequate online resources to replace some skill development activities (i.e. microscope use, inquiry-based experimentation) or specific elements of lab content (i.e. digital tissue images).	'Students struggled more to learn microscopy and much of the anatomy and critical thinking skills that come with in lab learning did not really occur, when labs were entirely online.' 'We need more quality online blood slides.'
Multiple faculty mentioned the lack of transferability of online lab credits to future programs (nursing, dental hygiene, etc.).	'Standards for nursing and dental hygiene programs will not accept online labs in our state (now that pandemic waivers have expired).'

Table 1. *Common themes and sample responses to the free response question, "Is there anything you would like to tell us about topics you moved online or wished you could move online?" Of the 176 respondents to the COVID-19 portion of the HAPS Curriculum & Instruction 2022 Laboratory Survey, 28 provided answers to this question.*

Of the 17 different selections of health precautions used in the in-person laboratory, the most frequently used were face masks, increased cleaning by staff or instructors, physical distancing, students cleaning workstations before leaving, and a decreased number of students in the lab (Fig. 4). Plexiglas™ shields for workstations and increased use of lab coats were the least frequently used. During the 2020-2021 and 2021-2022 academic years, the most common response to a COVID-19 related disruption to in-person teaching was to temporarily shift the infected, quarantined, or isolated student online (Fig. 5). Permanently shifting the entire class online was the most frequent response during only the partial academic year of March to August 2020. No disruptions to in-person instruction were reported by 10.1%, 12.9%, and 19.7% of respondents during the partial academic year and the 2020-2021 and 2021-2022 academic years, respectively. For all three time periods, students made up class work missed due to infection or quarantining by watching recorded videos (37.6%, 46.6%, and 44.4%, respectively) or completing work during an alternate time or location (82.6%, Fig. 6). The least common method (11.8 to 16.9%) for all three time periods was allowing each student a specified number of "dropped" scores for calculation of the course grade.

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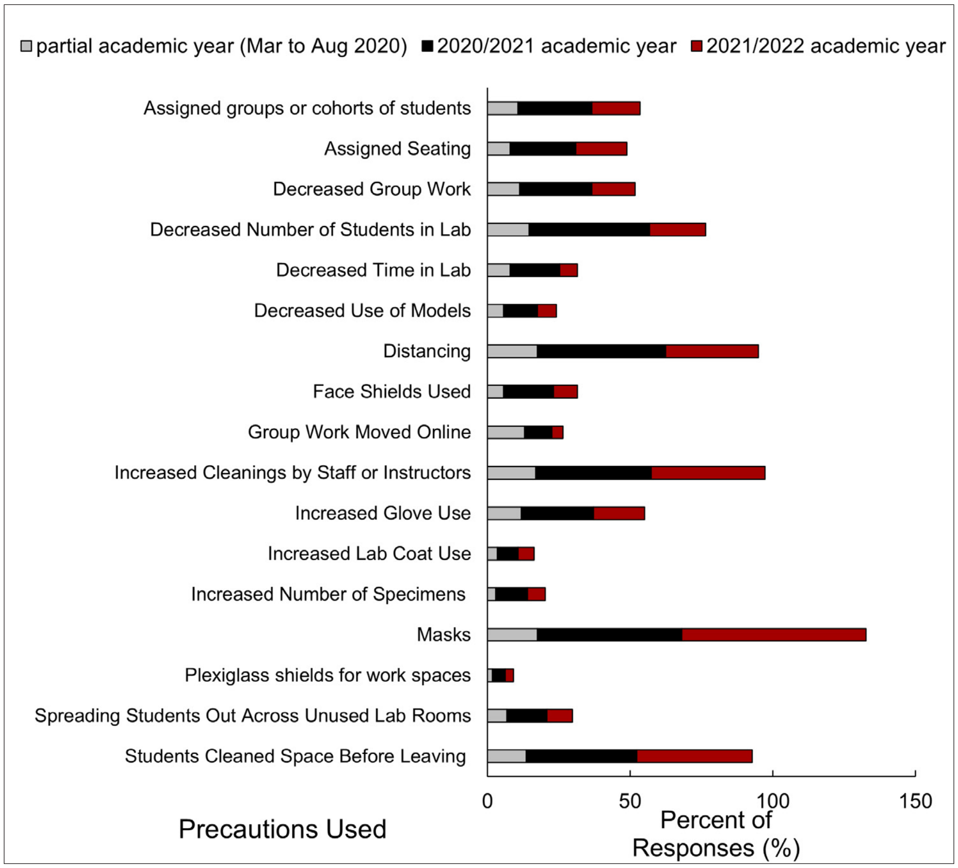

Figure 4. *Percent of survey responses (n=176) to the question, "What precautions did you take for in-person labs? SELECT ALL THAT APPLY."*

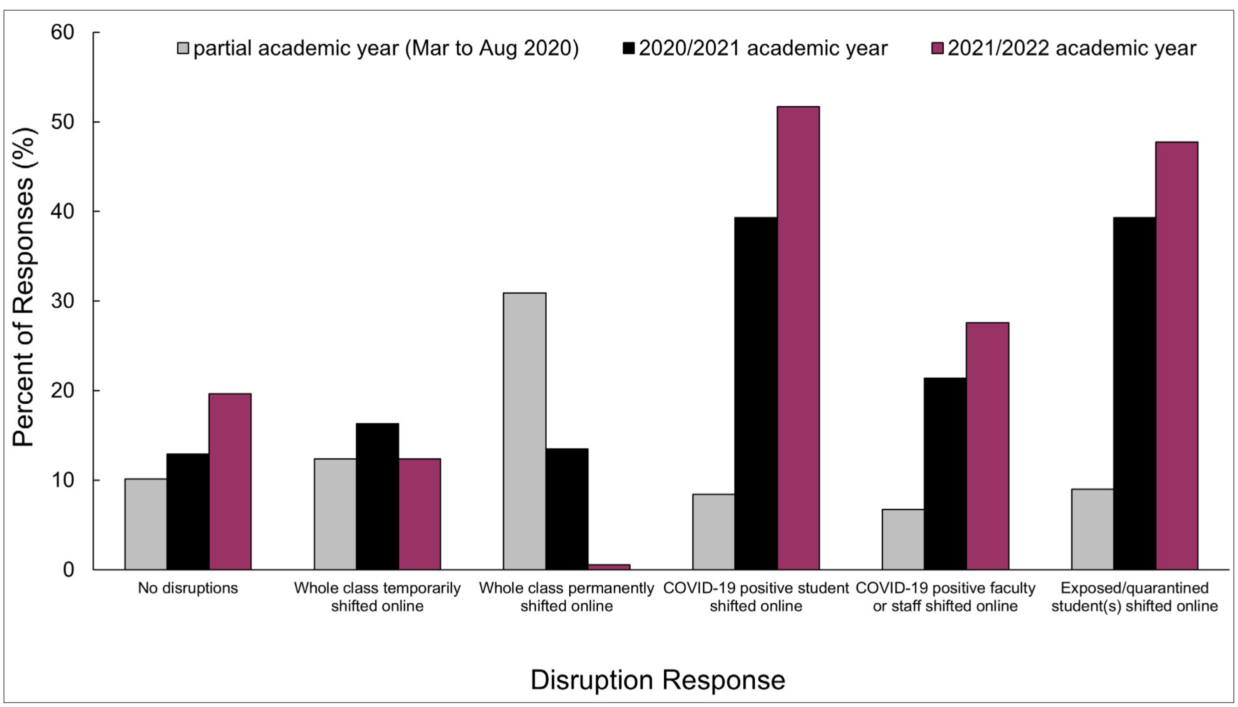

Figure 5. *Percent of survey responses (n=176) to the question, "If you taught in-person, either entirely or partially, during the following time frames of the COVID-19 pandemic, was in-person teaching disrupted due to positive cases among students, staff, or faculty? SELECT ALL THAT APPLY."*

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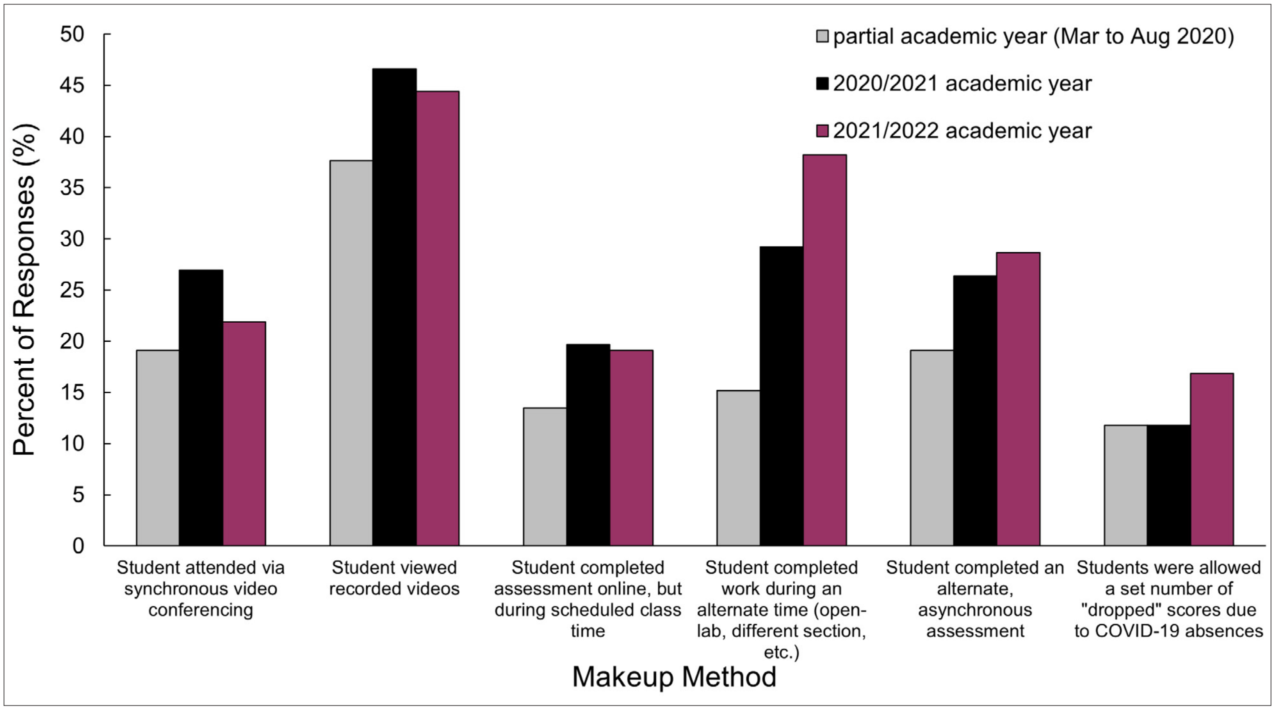

***Figure 6.** Percent of survey responses (n=176) to the question, "How did students make up work when absent due to quarantining or illness? SELECT ALL THAT APPLY."*

In methods of assessment, proctored online lab practicals were the most frequently used during the 2020 partial academic year (37.07%) and 2020-2021 academic year (39.9%), while in-person administration of lab practicals was most frequent during 2021-2022 academic year (57.3%; Fig. 7). For lab practicals that were administered in-person during the 2020 partial academic year and the 2020-2021 and 2021-2022 academic years, the most frequently used modification was a reduced number of students testing at one time (33.1%, Fig. 8). Beyond modification of lab practicals, quizzes (50%) and informal assessments (29.8%) were the most frequently modified (Fig. 9). If summative assessments, including lab practicals, were administered online, a lockdown browser (41.0%) or the honor system (no separate web browser or proctoring service; 25.8%) were the most frequently used administration methods (Fig. 10). Standardized assessment methods such as a HAPS exam (Human Anatomy & Physiology Society, 2023b) were implemented by 1 respondent as a result of the pandemic, while 20 considered but did not use a HAPS exam. Two respondents continued to use a HAPS exam during the pandemic. This survey question did not ask if the HAPS exam was used for lecture or lab assessment.

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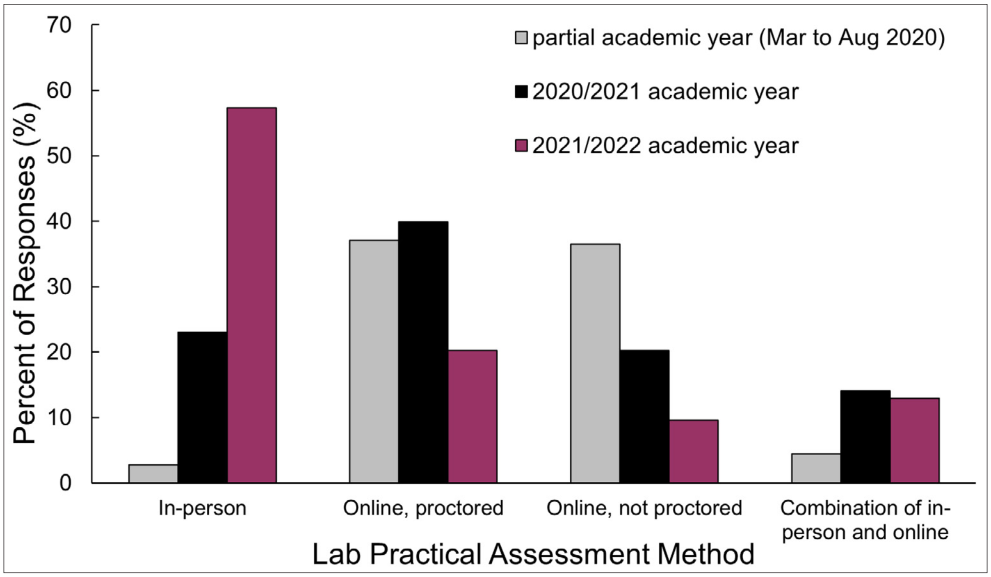

Figure 7. *Percent of survey responses (n=176) to the question, "During the following time frames of the COVID-19 pandemic, how were your lab practical assessments administered? SELECT ALL THAT APPLY."*

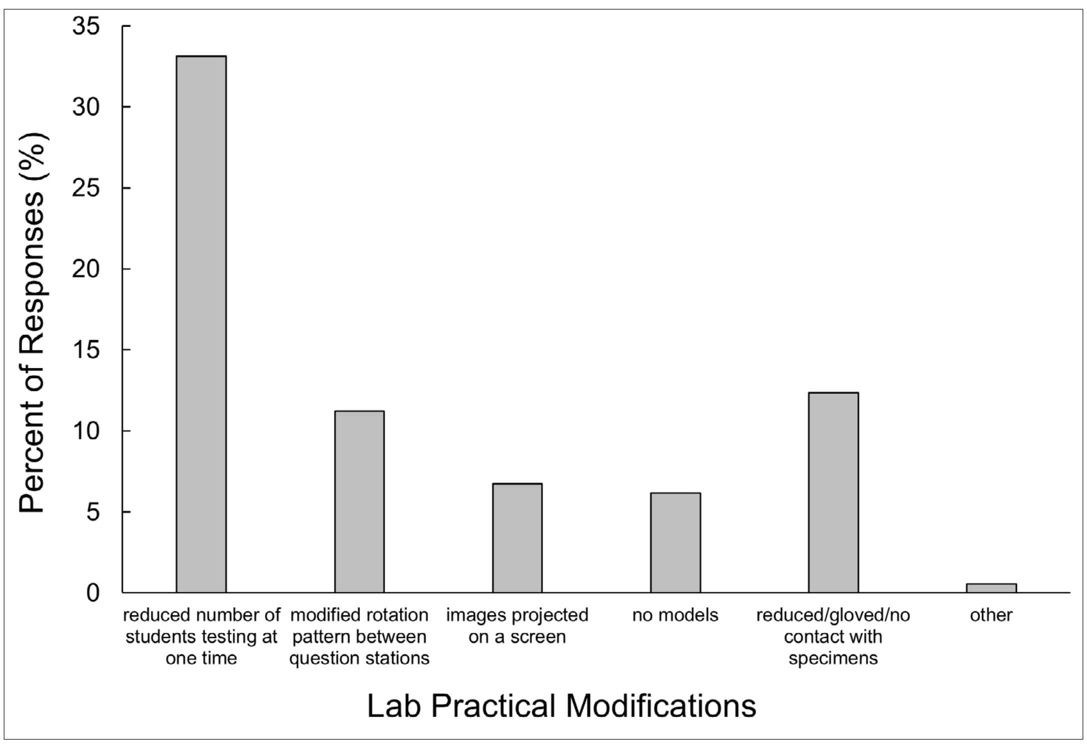

Figure 8. *Percent of survey responses (n=176) to the question, "If you gave lab practicals in-person, were there modifications to your testing format? SELECT ALL THAT APPLY."*

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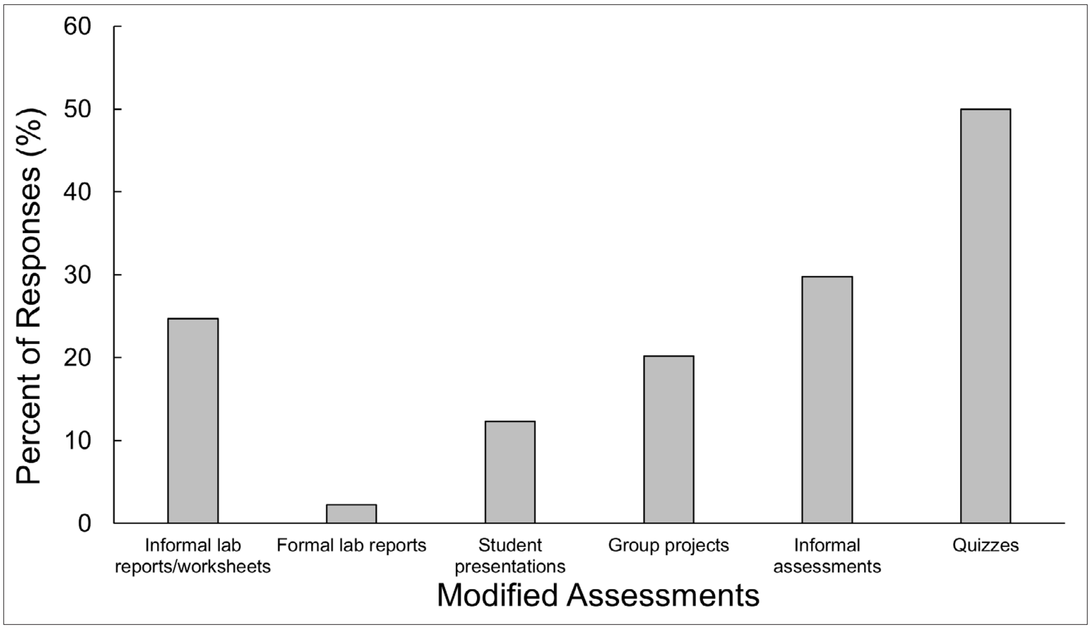

Figure 9. *Percent of survey responses (n=176) to the question, "Beyond lab practicals, what other assessments did you modify for administration during the COVID-19 pandemic? SELECT ALL THAT APPLY."*

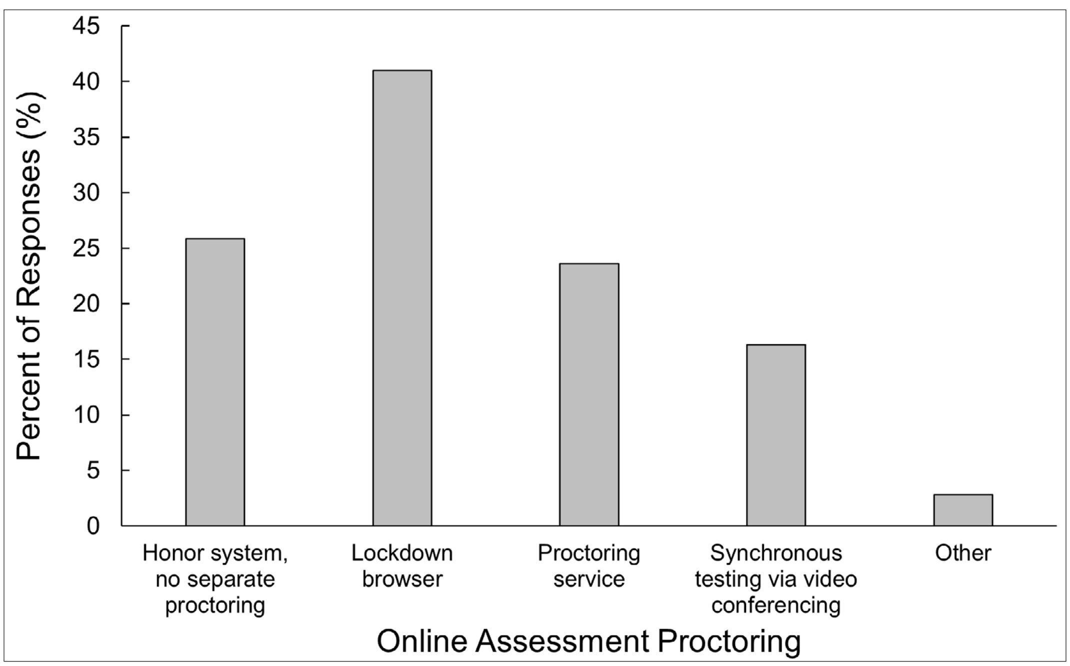

Figure 10. *Percent of survey responses (n=176) to the question, "If summative assessments (including lab practicals) were administered online, what proctoring service (if any) did you use? SELECT ALL THAT APPLY.*

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Perceptions regarding aspects of instruction that did not change during the pandemic included the number of learning outcomes met (49.4%) and the curriculum/grading rigor (42.7%; Fig. 11). The variety of testing and assessment methods was perceived to have increased by 37.1% of respondents, while expectations of student performance and average class grade were perceived to have decreased by 29.8% and 26.4% of respondents, respectively. The highest level of uncertainty regarding changes in grading rigor was with regard to the rate of D, F, and W grades recorded, where 12.3% of respondents were unsure.

Course formats once the pandemic was over, as compared to formats prior to the pandemic, were expected to be 100% in-person for all labs, except histology lecture and lab, as well as lectures for anatomy only and physiology only courses (Fig. 12). A combination of in-person and online was the most expected course format for A&P I and II lectures, as well as histology-only lectures and labs and 1-semester essentials lecture. A 100% online format was the least expected for any lecture or laboratory. When comparing course format prior to the pandemic (Britson et al., 2023a) and expected format after the pandemic, there is no difference for in-person (t = -0.601; df = 9; p = 0.562) and 100% online courses (t = 0.193; df = 9; p = 0.85). For hybrid courses, there was a significant difference in format prior to the pandemic and expected format after the pandemic [(t = =3.598; df = 9; p = 0.005), Fig. 13]. There were no hybrid format histology lectures or labs prior to the pandemic in our data set (Britson et al., 2023a).

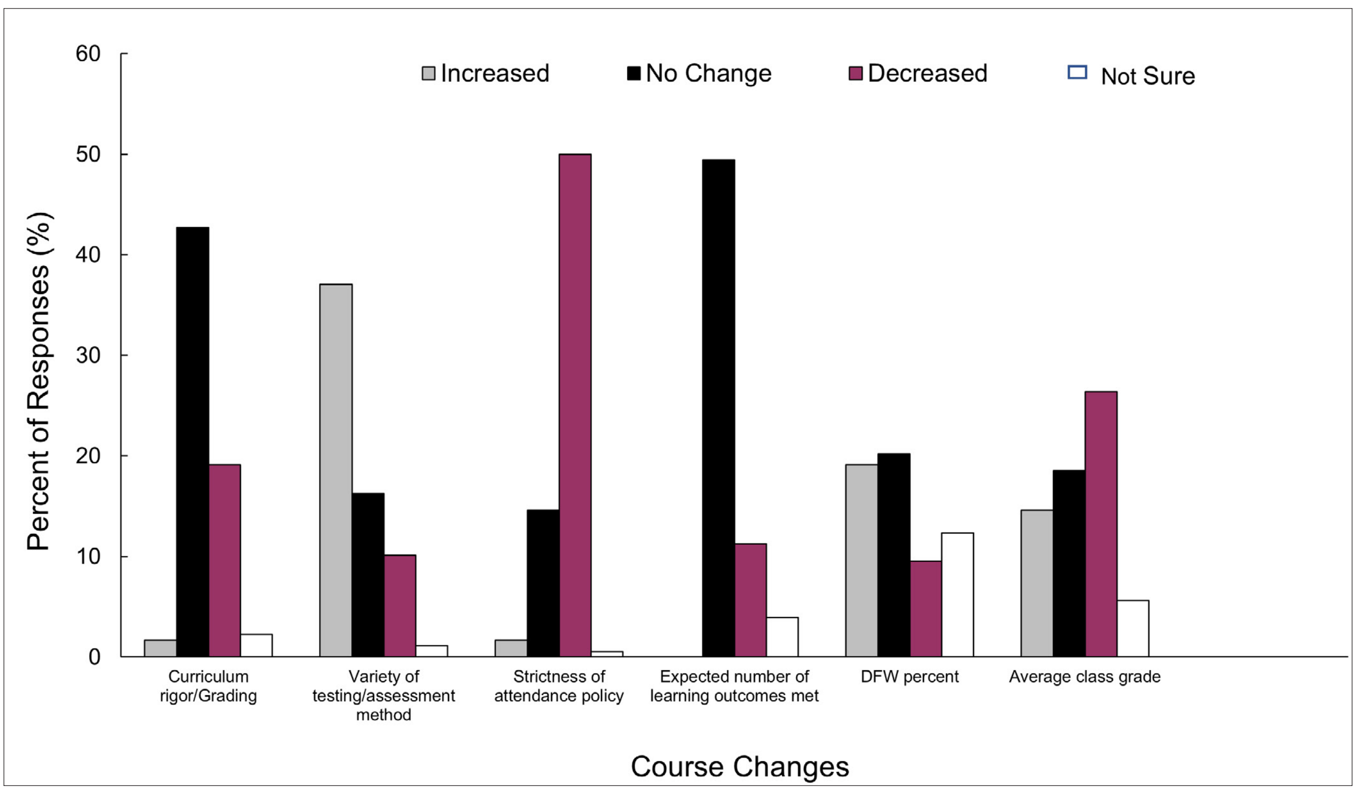

Figure 11. *Percent of survey responses (n=176) to the question, "Which of the following changed while teaching during the COVID-19 pandemic?"*

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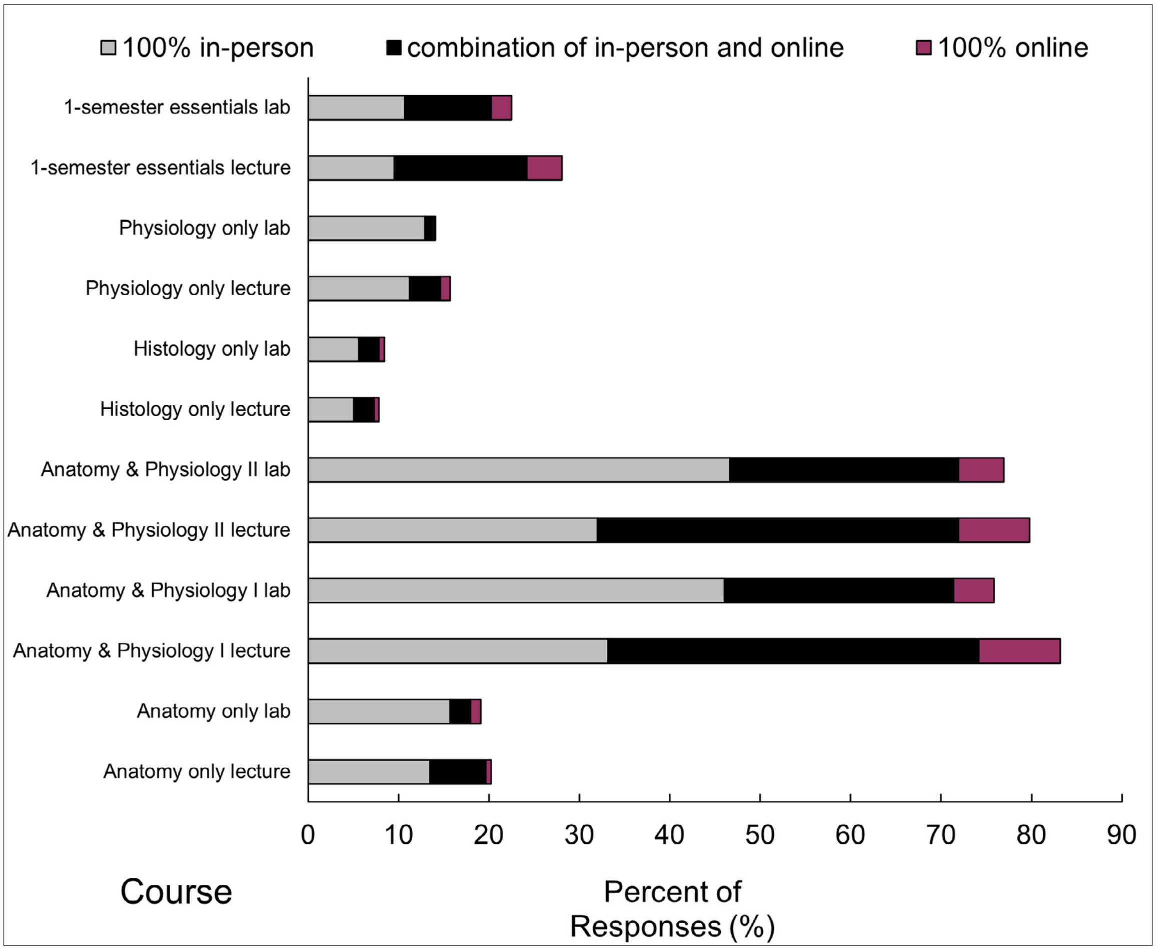

Figure 12. *Percent of survey responses (n=176) to the question, "For your INSTITUTION, please summarize expectations for course formats once the pandemic is over (as compared to before the pandemic). SELECT ALL THAT APPLY."*

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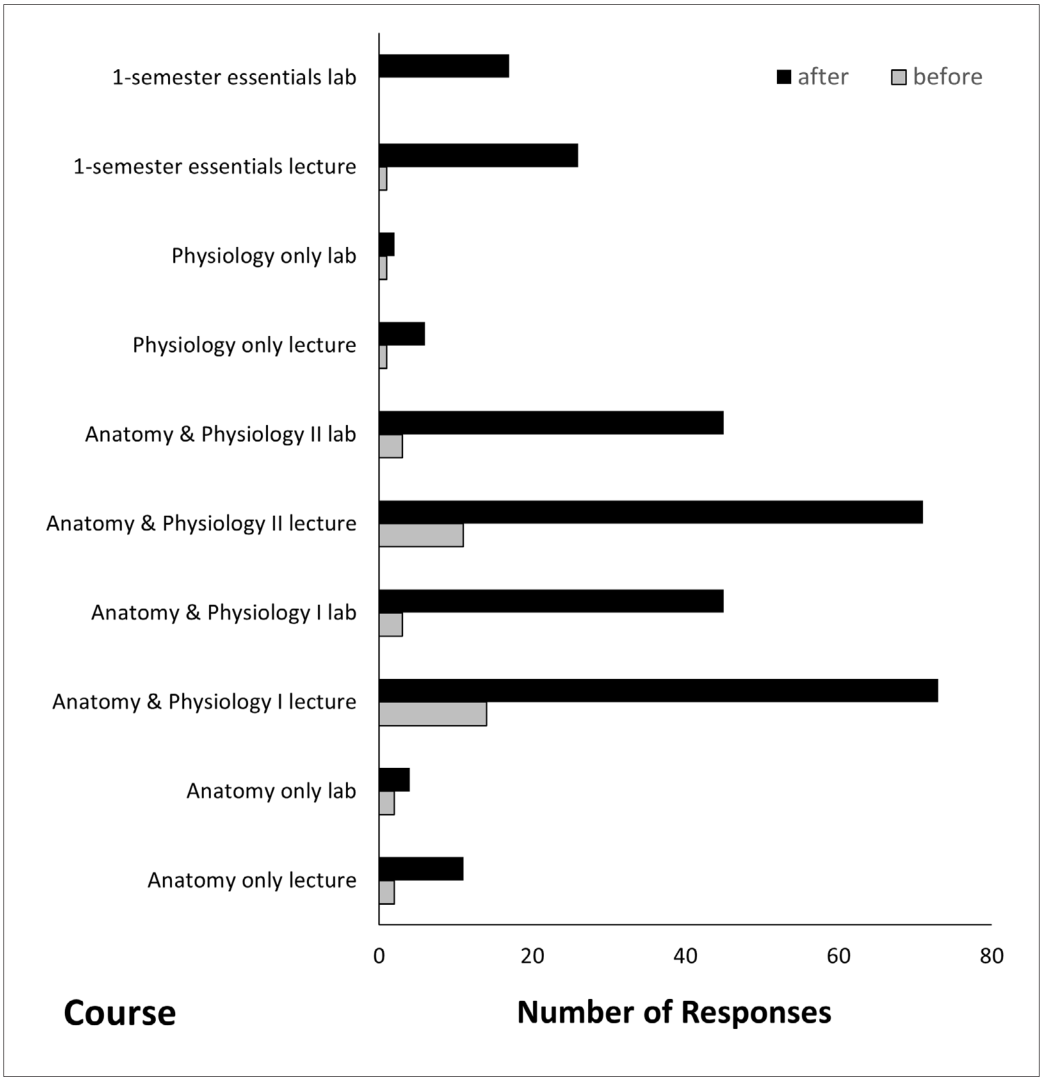

Figure 13. *Number of hybrid format courses prior to the pandemic (Britson et al., 2023a) and expected hybrid course format after the pandemic.*

When asked to characterize their responses to positive statements about the pandemic, respondents strongly agreed that they are more appreciative of in-person teaching. They agreed that they have become more compassionate educators who are more aware of inequities and conflicting demands, as well as methods to reduce inequities or demands (Fig. 14). Respondents were neutral to the impact of lab safety procedures and personal hygiene practices, as well as awareness and use of HAPS teaching resources. Respondents disagreed that they were more invigorated in their teaching as a result of the pandemic. Common themes of responses to the free-response question, "Will any of your modifications (e.g., resources, safety protocols, assessment methods) become permanent? Why or why not?", echoed the quantitative responses to the positive statements about the pandemic (Table 2). The outlier theme is that respondents expressed mixed feelings about institutions continuing online labs, as administrators appear to be making most of the decisions about lab modality rather than instructors.

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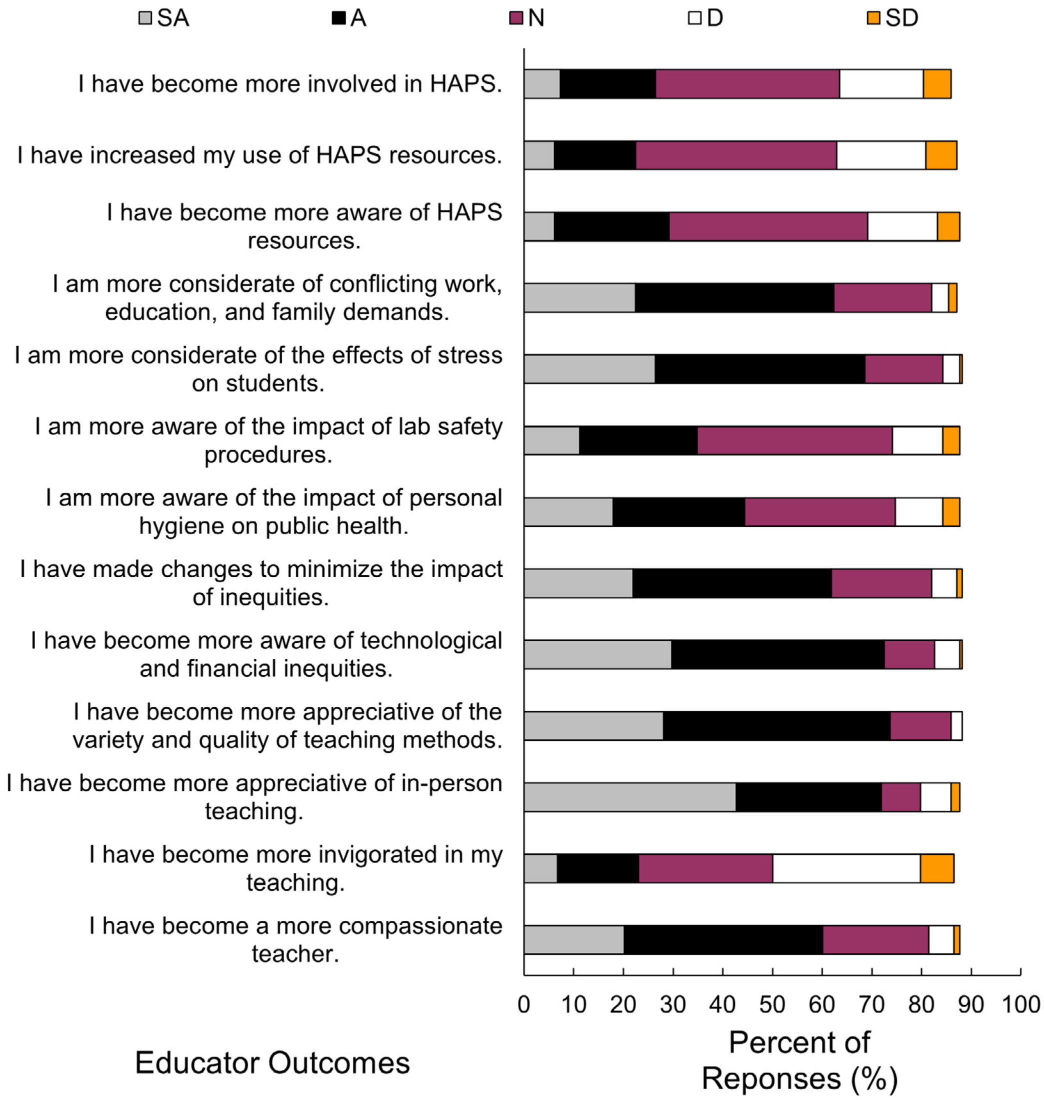

Figure 14. *Percent of survey responses (n=176) to the question, "There are positive outcomes from the pandemic. Please rate your response to each of the following statements."*

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Theme	Sample Response
Resources built by faculty during the pandemic (including study resources and computer-based assessments) will continue to be used in many instances.	'I have incorporated all of my online-created content into my face-to-face teaching to allow for better support and resources for students.'
Non-proctored online assessments will no longer be employed to prevent student cheating.	'I was left with a bad taste concerning online testing. Grades averages increased too dramatically during online testing.'
Multiple faculty mentioned continuing to be more flexible in their grading and attendance policies with students.	'...flexible attendance, flexible deadlines, two attempts on exams will be permanent. These reduce student stress and increase opportunities for learning.'
Faculty believe that pandemic-era resources increased the quality and equity of the student experience in the lab, which is a major reason for them to continue to employ many of them.	'Recording lectures seems a universal design. Students can all re-watch. Students who miss can get the exact experience. The saved images from class can be posted as lecture notes for all. This is staying. I also find it important with slides of tissues to project on the screen, so I can make sure things are not getting jostled. It also allows for an increase in size, so I don't have to worry about people shifting the focus or accidentally moving the slide. It helps visually impaired students as well.'
Multiple faculty mentioned providing COVID-era resources to students who miss a class (for illness) to keep them on track with their learning.	'Availability of online resources will be kept for future use for absent students unable to attend make-up labs.'
Faculty express mixed feelings about continuing online labs. Administrators appear to be making most of the decisions about lab modality, not necessarily the instructors delivering them.	'Now that it has been demonstrated that students can succeed using online methods, the administration has encouraged us to continue to make them available, despite the poorer outcomes, in order to increase enrollment and retention.'

Table 2. *Common themes and sample responses to the free response question, "Will any of your modifications (e.g., resources, safety protocols, assessment methods) become permanent? Why or why not?" Of the 176 respondents to the COVID-19 portion of the HAPS Curriculum & Instruction 2022 Laboratory Survey, 99 provided answers to this question.*

Discussion

Technological and Pedagogical Innovations

Teaching during and after COVID-19 pandemic restrictions produced a host of novel approaches used not just by A&P instructors, but by those across multiple disciplines (Davis & Pinedo, 2021; Harmon et al., 2021). The majority of these approaches revolved around the integration of technology into the educational environment and required instructors to learn new techniques (e.g., creating lecture videos), technologies (e.g., computer simulations) and different pedagogical approaches. If we ignore the institutional infrastructure issues (Coffey, 2023), modifications meant to meet the challenges of online and/or remote learning are a double-edged sword for students. While these modifications (e.g., online lecture presentations and videos, digital still images, simulation laboratory experiments) allowed students to have continuous access to course materials and opportunities for learning that were most conducive to their schedules, they also impressed upon the student the idea that learning is simply an independent effort of memorizing factual information while simultaneously reducing the amount and quality of interaction with peers and instructors that is required for true mastery of content information (Baum & McPherson, 2019; Beck & Roosa, 2020; Chang et al., 2022; Harmon et al., 2021).

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At the same time, the need to make such modifications led to a change in the infrastructure required for instruction and learning (Coffey, 2023). Notably, technologies needed during initial COVID-19 restrictions (i.e., computer hardware, digital resources, synchronous/asynchronous broadcasting software or platforms, etc.) meant not only that institutions of higher education needed to rapidly update their IT infrastructure to accommodate the transition, but also that students and instructors needed to obtain and/or learn to use specific equipment (e.g., computers, webcam, microphones, internet hotspots) necessary for either leading or attending courses being offered in these new formats (Coffey, 2023; Davis & Pinedo, 2021). There are some suggestions that the learning curve necessary to develop expertise with these resources may have been too steep to allow for optimal instruction or development of a learning environment to promote active learning and engagement (Beck & Roosa, 2020; Davis & Pinedo, 2021). The combination of diminished financial resources and unfamiliar learning environments may have contributed to the lower average grades and increases in letter grades of D, F, or W for students enrolled in A&P courses noted by respondents over the time period covered in the survey. For students whose institutions allowed students to opt into a Pass/Fail grade during all or a portion of the survey time period (e.g., University of Louisville and the University of Mississippi), the motivation to earn a specific letter grade may have decreased. These changes in academic performance are not isolated and have been seen in other reports on student performance during COVID-19 restrictions (Chang et al., 2022; Ghosh, 2022).

While there had been a rapid transition and expansion of technology infrastructure in March 2020, there had also been a growing awareness of the health concerns (both physical and mental) facing students and faculty from the early months of the pandemic. This awareness meant developing safety protocols to enable students and faculty to study safety in the lab, becoming more accommodating of the needs of students, and relaxing attendance policies and due dates. These changes ranged from providing students alternate routes to participate in synchronous courses and alternate assignments to replace device-specific learning activities to providing use of asynchronous educational activities (i.e., online simulations, discussion boards). We did, however, identify changes in the methods of assessment used to determine proficiency with course content. These efforts were undertaken by instructors surveyed here to ensure that students were meeting course expectations (e.g., grading rigor) and learning outcomes that were not modified in response to pandemic-related restrictions.

Assessment of Learning

Restrictions placed on in-person learning in March 2020 led to many changes in the methods of assessment of learning for our respondents, both in lecture and in lab across the initial, partial academic year and the following two academic years. We noted instructors using lockdown browsers and offering a greater diversity of assessment methods, including greater use of group assessment and alternative means for assessment beyond summative assessments. This increase in both informal, lower stakes assessments and group assessment has the potential, via student-centered and backwards design teaching techniques, to improve student mindset toward learning and not simply passing tests (Behrendt et al., 2020; De Castello et al., 2013; Finn et al., 2019; Graff, 2011; Long et al., 2020; Whetten, 2007; White & Maguire, 2021). The latter seems to be a common mindset among students whose educational focus following completion of A&P happens to be nursing (Behrendt et al., 2020). Along with the increase in lower stakes, informal assessment, there were modifications to in-person laboratory practical assessment procedures. Not only were there changes to the format (i.e., use of models, microscopic images, and dissected specimens or donated bodies) but there were also changes in the structure of the practical assessment (i.e., number of stations, questions, number of students completing the practical exam at one time).

While modifications to assessments appear to have been done in compliance with physical restrictions in place due to the COVID-19 pandemic, they may have had an unintended effect on the mental stress of students. Reduced student performance may have resulted from a combination of changing expectations from instructors during COVID-19 restrictions, a greater reliance on online and hybrid instruction in students' course loads, and emotional responses to COVID-19 restrictions causing extraneous cognitive load (Skulmowski & Xu, 2022). Further still, the implementation of restrictive and invasive monitoring practices frequently used to proctor online assessments often generates barriers to student performance and potentially negates any benefit arising from the use of lower stake assessments. In the present study, over 80% of respondents indicated that they monitored students online synchronously, through a proctoring service, or by utilizing software to lockdown computer browsers to only allow access to the LMS tab during assessment.

Student Enrollment Trends

Understanding how to approach the changing educational environment for A&P, an environment unlikely to return to pre-COVID-19 patterns, is important not only for institutions to plan course offerings, fund laboratories, and hire faculty, but also for individual instructors to develop engaging and appropriate curriculum necessary to train future scientists, educators, and healthcare professional across various modes of instruction [e.g., face-to-face, hybrid, remote/online; (Beck & Roosa, 2020; Harmon et al., 2021; Hurtt & Bryant, 2016)]. National trends for all courses in higher education show a growing number of students electing, potentially as a learning choice, to take courses either in a

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hybrid format or entirely remotely/online, with institutions of higher education increasing the offerings for courses in these formats (Liachovitzky & Wolf, 2019; National Center for Education Statistics, 2023). In our data, we see a parallel trend not only through the increased offering of A&P courses in multiple formats, even when respondents indicated less-than-optimal learning performance by students, but also with respondents indicating that they plan on integrating online and hybrid learning techniques into their face-to-face and in-person learning experiences (Tables 1 and 2).

Some modifications, which were already being implemented prior to the COVID-19 restrictions, became more pronounced within the laboratory after March 2020 (Liachovitzky & Wolf, 2019; Rowe et al., 2017; Singh et al., 2021; Stokes & Silverthorn, 2021; Zhang et al., 2021). Additionally, some techniques such as recorded lecture videos, as one respondent wrote, allow for integration of a more inclusive learning environment for students through the application of universal design (Table 2). Furthermore, thorough integration of technology into the curriculum allows for diversity in learning experiences, creating the potential to increase engagement with students that are technologically dependent learners and provide avenues to expand laboratory instruction beyond the walls of the classroom (Persinger et al., 2021; Singh et al., 2021; Stokes & Silverthorn, 2021).

The COVID-19 pandemic led to an increase in students choosing to take at least some of their classes online. Online or remote courses and programs experienced a surge in the number of students interested in this education modality during the COVID-19 pandemic and post-pandemic period. According to the National Center for Education Statistics, in Fall 2021, 61% and 28% of all undergraduate students enrolled in at least one, or all, online or remote course(s) respectively, representing an increase from Fall 2019, in which 36% and 15% of all undergraduate students were similarly enrolled (National Center for Education Statistics, 2023).

The increase in the offerings of distance education courses observed during the initial period of the pandemic has continued even after the peak of the COVID-19 pandemic had passed. In 2018-2019, 79% of colleges and universities offered at least one distance education program or a distance education course (Ruiz & Sun, 2021). In the 2019-2020 academic year, 84.1% of academic institutions moved all or some in-person classes to online-only (Cameron et al., 2019), and at the beginning of the COVID-19 pandemic, Spring 2020, 77% of American schools transitioned to *online-only* instruction (Department of Education, 2022). According to the "Changing Landscape of Online Education (CHLOE)" annual report, which polled hundreds of chief online officers in higher education on their experiences during the 2021-2022 academic year, 66% of institutions are taking advantage of the increased popularity of online learning to grow and sustain *overall* enrollment by adding new online programs based on students' demand in order to balance stagnant or declining in-person programs (Legon et al., 2023). Additionally, 42% of institutions are creating new versions of their most popular on-ground degrees (Legon et al., 2023).

According to our results from the lab survey, instructors summarized their expectations for course format once the pandemic was over by responding that they expected 100% in-person for all physiology-only and anatomy-only labs. They did not expect physiology-only lectures to meet 100% in-person. Respondents expected that A&P I and II lectures, histology-only lectures/labs, and 1 semester essential lectures would be taught in a combination of in-person and online course format. For any lecture or laboratory course, a 100% online teaching format for future course offerings was the least expected. Upon comparing data obtained on course format expected after the COVID-19 pandemic versus the course format before (Britson et al., 2023a), no difference for in-person and 100% online courses was observed. When a similar comparison was made for hybrid courses, a significant difference was observed as there were no hybrid histology lectures or lab courses prior to the pandemic (Britson et al., 2023a).

The institutional and faculty transition to online learning has led to many parallel changes at the student level. A recent Educause survey documented a 220% increase in student preference for courses completely or mostly online since the onset of the pandemic, from before March 11, 2020, to 2022 (Kelly, 2022), though it is not clear if convenience alone is driving this preference. In the same period, there has been a 65% drop in the number of students that completely prefer face-to-face learning (Kelly, 2022). Having to take classes in the online format increased the confidence of students in the efficiency of online learning and other benefits as well. Students who were forced to change their living structure and personal lives to make online learning more convenient and therefore more desirable, continued with these changes and made the choice of continuing with distance education courses and programs after COVID-19 vaccines were widely available. Students with family members with comorbidities putting them at high risk of complications from an infection could choose to continue with online learning instead of exposing their family to the disease. Non-traditional learners with family responsibilities could choose to continue with online learning, especially after experiencing the convenience of this form of learning during the lockdown.

Meeting Educational Needs of all Students

Another aspect of higher education impacted by the pandemic was meeting the needs of students who required accommodations under the Americans with Disabilities Act (ADA) (Burgstahler, 2021; Tarconish et al., 2022). Remote learning during the pandemic has been noted as placing undue burdens on students who required accommodations

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by either forcing students, educators, and/or institutions to seek alternate avenues to learning or requiring the purchase of equipment necessary for completion of tasks that would not be required under normal educational settings. Many institutions required educators to master the use of technology for the transmission of information, expand how they communicated with students, or provide digital resources from which students could learn and master understanding of content independent of direct instruction. Thoughtfully developed, use of these technologies allows for seamless integration of online communication and dissemination of information for all students (Burgstahler, 2021; Gullo, 2022; Tarconish et al., 2022). At the same time, the remote learning environment was noted as providing students with physical limitations with more options to access information that would have otherwise been unavailable to them (Burgstahler, 2021; Rice & Dunn, 2022).

A use of technology that some have expanded upon with the return of face-to-face instruction is incorporating video recording of lecture presentations with live closed-captioning and using, to varying degrees, aspects of the ever-growing online and electronic tools for laboratory instruction. Thus, the integration of technology, both in terms of software and hardware, has allowed instructors to meet many of the guiding principles of Universal Design for Learning (UDL), centered on flexibility of instruction, communication with students, and use of multiple modalities of instruction (i.e., visual, auditory, tactile sense utilization) (Bowen, 2017; Gernsbacher, 2015; Human Anatomy & Physiology Society, 2024; Rose et al., 2006). Educators are cautioned, however, to be mindful of "fatigue" or "burnout" associated with video communication that may diminish student engagement. The lower completion rate traditionally observed with online courses (Jordan, 2015; Parkinson 2014), including online A&P I (Ediger, 2022), may corroborate these concerns.

Simply allowing the enthusiastic integration of technology by itself, however, will not necessarily lead to a more accessible learning environment for all students, especially for those that are given accommodations under the ADA (Burgstahler, 2021; Tarconish et al., 2022). For example, many screen readers and captioning software applications struggle with interpreting A&P terminology. While the technologies introduced and refined throughout the online educational environment of the pandemic may not be the tools necessary for forming an inclusive learning environment for all students, the integration of the technology with UDL principles can, however, increase accessibility within the learning process (Bowen, 2017; Gernsbacher, 2015; Human Anatomy & Physiology Society, 2024; Rose et al., 2006). Moreover, students with diagnosed disabilities may yet need additional resources and accommodations to be successful in a course that is remote or that emphasizes technology in the learning environment (Gullo, 2022; Tarconish et al., 2022). Lastly, the integration of technology into the laboratory curriculum needs to be vetted to ensure that the technology meets the specific principles of UDL and does not automatically instill an unintended barrier to students who are already at potential disadvantage in needing accommodations through ADA.

Conclusions

Teaching through a pandemic changed us as A&P educators. The experience left us more appreciative of in-person instruction as well as more aware of the financial and technological inequities affecting our students and pushed us to investigate ways to minimize these inequities. The HAPS C&I subcommittee on Teaching Accommodations, in addition to holding four Town Hall meetings in 2022 and developing the Accommodations Handbook (Human Anatomy & Physiology Society, 2024), has investigated the use of screen readers for accessibility and UDL resources for lab instruction both in-person and online. The C&I Teaching Tips subcommittee added a new question for submissions that asks if the tip can be used online or online with modification. Development of these resources has the potential to allow us, as A&P educators, to incorporate principles of resilient pedagogy (Thurston et al., 2021) into our courses, thus minimizing the effect of disruptions to the educational experience of our students. At the same time, as we have become more understanding as educators, and more aware of the effects of stress and conflicting demands on our students, we have not become more invigorated in our teaching. Increased calls for developing trauma-informed pedagogical approaches to reduce the effects of pandemic-related stress and burnout in our students (Arbour et al., 2023) exist simultaneously, and in contrast with, post-pandemic predictions that educators will experience increased rates of exhaustion, stress, and burnout in the next five years (Wiley, 2024). While Wiley (2024) has self-identified easy-to-implement, publisher-provided resources as one means of supporting instructors through this time, support must also come from institutions, administrators, and colleagues to fully recover from teaching during the COVID-19 pandemic.

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Metabolic Data Associated With a 400-Meter Dash and its Application within a Guided Inquiry Lesson

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Abstract

This study revises and enhances a guided inquiry activity designed to introduce undergraduate and high school students to the physiological concepts of exercise fatigue during a 400-meter dash. This activity has been employed since 2016 in entry-level human physiology courses at the University of Minnesota and across 30 high schools. Using simulated data, students analyze variables such as blood lactate, pH, heart rate, and oxygen consumption to identify factors contributing to fatigue in a 400-meter dash. Recognizing that limitations existed in the original dataset (e.g. blood lactate and ventilatory data that rose too high or too quickly), this work incorporates revised data derived from a treadmill-based 400-meter dash, supplemented with peer-reviewed benchmarks to better reflect physiological responses in the severe and extreme exercise intensity domains. The updated activity includes adaptations for both entry-level as well as upper-level human and exercise physiology courses. The upper-level version introduces students to exercise intensity domains. These revisions provide students with a data-driven exploration of the mechanisms underlying exercise fatigue and expand opportunities for analyzing and interpreting data. The activity aligns with Next Generation Science Standards by fostering skills in data analysis, collaborative learning, and critical thinking. Future directions include further refinement of the dataset using real-world physiological measurements, enabling an even closer alignment with contemporary exercise science research. https://doi.org/10.21692/haps.2025.007

Key words: guided inquiry curriculum, analyzing and interpreting data, exercise physiology, dual enrollment programs

Introduction

"Analyzing and interpreting data" is one of the eight Science and Engineering Practices promoted within the Next Generation Science Standards publication (NGSS Lead States, 2013). Gathering valid data for analysis in entry-level anatomy and physiology classes is problematic for a variety of reasons, including student inexperience. In 2016, a graduate student in exercise science was employed at the University of Minnesota to use journal articles to develop data sets to accompany a hypothetical 400-meter dash (400m) engaged by two individuals of different physical fitness. That dataset has been used in a guided inquiry activity in an entry-level physiology class taught both at the University of Minnesota and within a dual enrollment program involving 30 high schools (Jensen, 2024; Jensen et al., 2013). In total, the activity has been used by about 1000 students per year since it originated in 2016.

Because of its regular and widespread use, revision of the activity was warranted, especially when updated data is available. This article describes the guided inquiry exercise and provides a current view of the cause of physical fatigue during exercise and concludes with a revised data set and a revised activity. Two versions of the final activity are reported: first, a version that targets the original entry-level physiology course, and, second, a version for a higher-level human physiology course.

Background and Setting

Guided inquiry is a teaching strategy founded on constructivist learning theory (Vygotskiĭ, 2012) and uses carefully constructed questions that follow a learning cycle, a highly structured learning system originally developed by Piaget (Lawson et al., 1989). Questions are intended to

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promote conversations between students who are working within small cooperative groups. Through the process of answering questions, students are introduced to terminology and concepts that are central to the discipline. The role of the instructor during an inquiry lesson is to initially organize the groups, introduce the activity, guide discussions within the groups, and provide closure at the end of the activity. Aerobic Fitness During a 400-Meter Dash is a guided inquiry activity developed using the learning cycle.

All instructors using the 400m activity were experienced with guided inquiry pedagogy and adept with organizing and facilitating cooperative student groups. Classes in the dual enrollment program were implemented in regular high school classrooms with an enrollment of between 15 and 35 students. At the University of Minnesota, students were in active learning classrooms that featured round 9-person tables and a total class size of 60 students. Keeping with best practices in cooperative group learning, student groups at both the University and within the high schools (dual enrollment) were limited to two or three students per group and students were assigned individual roles such as reader, manager, and reporter (Johnson & Johnson, 2018).

The original 400m activity directs students to investigate why Runner Two, the male, appeared considerably more exhausted than Runner One, the female middle-distance track athlete. The original activity (Appendix 1) first asks them to predict how blood lactate concentration ([BLa-]), arterial hemoglobin saturation, heart rate, stroke volume, blood pH, blood glucose, oxygen consumption (VO_2), and minute ventilation will change during the race. Then, the students graph the trends in each variable from a simulated data set throughout the race before assessing their predictions. For example, students should find that heart rate, VO_2, [BLa-], and ventilation all increase, while blood pH decreases. In addition, they should find that the heart rate, [BLa-], and blood pH responses are distinct between the two runners. Finally, they identify variables that distinguish the fitness between the two runners and which variable(s) best indicate(s) why Runner Two was exhausted compared to Runner One. This ultimately leads to discussing the role of pH in muscle fatigue. Murray uses this activity in the second week of the semester as an introduction to data in physiology, fitness, and graph interpretation. In contrast, Anton introduced the revised activity for the upper-level human physiology class in the fourth and final unit after first completing a lesson on metabolism more generally.

Through discussions between authors, it was noted that the original simulated data exhibited limitations typically absent from real data. For example, blood lactate concentration and several ventilatory variables such as VO_2 rose too high or too quickly. Therefore, it was decided that along with a revision to the 400m data set and activity for the entry-level physiology course, a new activity should be generated using the same data set for a more advanced human physiology course taught at the University of Minnesota. The focus of the more advanced activity would be exercise intensity domains and an introduction to central versus peripheral fatigue.

Appendix 2 contains the activity and dataset intended for use in the entry-level physiology course, and Appendix 3 contains the activity and data set intended for use in the more advanced human physiology course. Assessing the intended learning outcomes for these activities was conducted informally through interactions with the instructors, classroom discussions, or clicker-style questions. It should be noted that it was not the purpose of this paper to compare the original to the updated version in the introductory class.

Underlying Physiology and Limitations with the Original Simulated Data

Two significant concepts underlying this activity are exercise intensity domains and peripheral versus central fatigue. Exercise intensity domains characterize distinct physiological *responses* to exercise (Ozkaya et al., 2023), while the concept of peripheral versus central fatigue denotes fatigue *origin*. Peripheral fatigue occurs at or distal to the neuromuscular junction while central fatigue occurs proximally to that junction (Taylor et al., 2016). These ideas are also linked, whereby exercise in different intensity domains typically corresponds to varied contributions of central versus peripheral fatigue. In general, central fatigue accumulates with long-duration, low-intensity exercise, while peripheral fatigue dominates during exercise of short-duration and high intensity (Bigland-Ritchie et al., 1978; Iannetta et al., 2022).

Exercise Intensity Domains and Peripheral Fatigue

Exercise intensity domains are usually characterized by particular blood lactate and ventilatory responses (Ozkaya et al., 2023). Concerning lactate and VO_2, the "moderate" domain spans rest until the first elevation in blood lactate, while VO_2 increases and reaches a steady state within 2-3 minutes (Jamnick et al., 2020). The "heavy" domain comprises blood lactate levels that are elevated above resting but that can stabilize. Oxygen consumption again increases and reaches a steady state, but this may take 10-20 minutes due to a "slow component" (Burnley & Jones, 2018). If exercise intensity rises further into the "severe" domain, blood lactate levels progressively increase, and VO_2 will eventually rise to VO_2 max. Finally, the "extreme" domain includes all exercise so intense that blood lactate cannot stabilize and fatigue results before reaching VO_2 max. Concerning time to exhaustion, moderate efforts can last many hours, heavy efforts approximately 40 minutes to three hours, severe efforts about 2-40 minutes, and extreme efforts about two minutes or less (Burnley & Jones, 2018).

Peripheral fatigue is more closely linked to exercise across intensity domains (Iannetta et al., 2022). In contrast, central fatigue appears to play a similar role in fatigue for exercise in the moderate, heavy, and severe domains but negligible

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(Iannetta et al., 2022) or small contributions to events such as a 400m dash (Tomazin et al., 2012). For peripheral fatigue, severe and extreme efforts substantially increase both intramuscular and blood [H^+] and [BLa^-], extracellular [K^+], and intramuscular inorganic phosphate concentration ([P_i]), among other metabolites (Black et al., 2017; Vanhatalo et al., 2016). The simulated data included in the original activity correctly exemplified peripheral fatigue via decreased blood pH and increased [BLa^-] in both runners, but especially in Runner Two. However, [BLa^-] increased too quickly and too much in the original data: [BLa^-] usually peaks around four minutes *after* a 400m dash and a value of 20 mmol/L suggests a much faster time (Gupta et al., 2021).

It is important to reiterate that although lactate and H^+ accumulate with increased reliance on anaerobic glycolysis, lactate itself has minor effects on fatigue and can even mitigate fatigue (Ferguson et al., 2018). Growing acidification alone contributes directly to peripheral fatigue but plays a minor role (Fitts, 2016). Rather, elevated [P_i], especially in combination with elevated [H^+], induces greater impairments to muscle shortening velocity and power (Debold et al., 2016). Such effects impair calcium handling and actin-myosin cross-bridge binding (Debold et al., 2016; Ferguson et al., 2018). Accumulating extracellular [K^+] from repeated stimulation impairs excitability by depolarizing myocytes, thus impeding Na^+ channel reactivation (Ferguson et al., 2018). Finally, other accumulating metabolites, such as ADP (Allen et al., 2008) and reactive oxygen and nitrogen species (Powers & Jackson, 2008), also induce peripheral fatigue. Despite its weak contribution or even buffer against fatigue, lactate remains among the best *indicators* of fatigue, exercise intensity, and the contributions of anaerobic metabolism.

Based on the original simulated data, the [BLa^-] and pH response in Runner One suggested that they worked in their severe or extreme domain as their [BLa^-] rose above maximal steady-state lactate values for trained endurance athletes (Czuba et al., 2009). However, this conflicts with their modest increase and near steady-state attainment in cardiovascular and respiratory variables as those responses more closely matched the moderate or heavy domain. Despite this conflict, the original simulated data still communicated that Runner One, depicted as female, relied relatively more on aerobic metabolism, thus avoiding substantial peripheral fatigue. In contrast, the simulated data for Runner Two, depicted as male, clearly exhibited someone working in the extreme domain: the overall effort lasted less than two minutes, their [BLa^-], cardiovascular, and most respiratory variables increased substantially, while their blood pH dropped more dramatically. Notwithstanding the dramatic increases, the maximal stroke volume, corresponding cardiac output, and minute ventilation (VE) observed appeared low for a typical young male.

Therefore, despite capturing some core aspects of peripheral fatigue and communicating the fitness difference between the two runners, the original simulated data missed trends present with real data. For example, the maximal VE of 82 L/min for Runner Two, depicted as a young male, was quite low as it fell between the 5^{th} and 10^{th} percentile for males between 20-29 years of age (Kaminsky et al., 2018). Runner Two's changes in their VO_2 response to exercise demand (the VO_2 kinetics) were also too fast and they nearly reached a plateau. Maximal 400m efforts are in the extreme intensity domain and VO_2 max plateaus should therefore not be observed.

Runner One's VO_2 kinetics are likely faster than Runner Two's given their better cardiovascular fitness (Jones & Burnley, 2009), meaning they can reach a steady-state VO_2 in less time. However, assuming Runner One exercises in their severe domain, the data should not depict a near plateau in their VO_2 response (Ozkaya et al., 2023). Furthermore, a severe domain response should elicit larger increases in heart rate for apparently young, endurance-trained females.

Central Fatigue

Central fatigue also contributed to Runner Two's fatigue (Tomazin et al., 2012), but likely less than peripheral fatigue during a 400m dash. Central fatigue is a reduced neural drive to the contracting muscle (Taylor et al., 2016). This decreased volitional activation manifests as a lower maximal force or power output and changes in electromyographic activity (Dotan et al., 2021). Progressively impaired muscle activation, relaxation, and coordination would, therefore, reduce running speed.

Measuring volitional activation usually entails the twitch interpolation technique (Dotan et al., 2021). Briefly, subjects consciously contract a muscle as hard as possible, producing a maximal voluntary contraction (MVC). During this maximal contraction, an electrical stimulus is delivered to the muscle, which may yield a higher, "twitchlike" force output. The greater the difference between this interpolated twitch torque and the MVC torque, the greater the central fatigue. A study showed that a 400m dash induces greater central fatigue than shorter sprints (Tomazin et al., 2012). Though central fatigue contributes to fatigue during a 400m dash, we are unaware of data comparing maximal to submaximal 400m dash efforts in untrained and trained participants, respectively. Future amendments to this activity could include MVC, percent voluntary activation, and similar measures.

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Revised Data

Revisions to Runner One's Data

We remade Runner One's simulated data by slightly reducing the fitness of an elite-level female endurance athlete (Furrer et al., 2023) to depict a highly trained female exercising in the severe domain, but not to maximal effort. For example, some of the peak values in Runner One's data now are a stroke volume of 118 mL/beat, a cardiac output of 20 L/min, and a VE of 93.6 L/min. In contrast, elite females exercising at maximal effort can report stroke volumes of ~125 mL/beat, cardiac outputs of 25 L/min, and VE of 125 L/min (Furrer et al., 2023). Although the trends and peak values depicted in this new data better reflect a highly trained female endurance athlete running a submaximal 400m dash, the data for Runner One could improve from collecting real data from this population.

Revisions to Runner Two's Data

Given the simulated data limitations, author Anton Hesse, a previous 400m hurdler, ran a fast 400m dash on a treadmill while collecting data on a metabolic cart to revise Runner Two's data, as Anton is male, and Runner Two is depicted as such. As expected, the rise in VO_2 and the VE data did not plateau. Despite improvements, the new data is not without limitations. Perhaps, most importantly, Anton did not run a truly maximal effort 400m dash. Running to exhaustion on a treadmill always brings some risk of falling, but especially so at high speeds. Anton was also more fit than Runner Two. Running close to maximal effort was necessary to capture the best possible data, but Anton's higher fitness required rescaling some ventilatory variables and the running speed to lower values to reflect the fitness depicted by Runner Two.

We also reduced Anton's VO_2 relative to body mass by inflating his body mass from 78.9 to 85 kg. Together, the rescaling and inflated body mass reduced the peak VO_2 from 55 to 40.9 mL/kg/min, or the ~90th to the ~35th percentile if these values were treated as VO_2 max. In addition, Anton warmed up before the 400m dash to minimize injury risk and also reexperienced some form of pre-race jitters and hyperventilation, explaining his relatively high starting heart rate and respiratory exchange ratio (RER) values. Although high, his heart rate was in the range of previously reported data before a 400m dash (Gupta et al., 1999). Although this warm-up likely increased his preparedness to run a fast 400m dash, the high starting heart rate and RER values can be seen as a limitation because they are far above resting levels and may, therefore, confuse students.

Unfortunately, our lab did not have a pulse oximeter compatible with our metabolic cart, nor was our equipment capable of measuring stroke volume. Although a pulse oximeter measures peripheral oxygen saturation (SpO_2) to closely approximate the oxygen saturation of arterial blood (SaO_2), it would nevertheless show that SpO_2 often changes little during exercise, especially in untrained athletes (Abe et al., 2022; Williams et al., 1986). For stroke volume, we used published data to show that stroke volume in untrained males often plateaus around 120 mL/beat (Gledhill et al., 1994; Zhou et al., 2001).

Revised Activities

The new data provided in this revised activity will serve any general physiology class. However, we expect exercise physiology students could also benefit from discussing the nuances in the physiological responses to exercise in different intensity domains as these are beyond the scope of most introductory physiology classes, even those at higher levels. Specifically, we included additional variables [VO_2 relative to body mass (relative VO_2), respiratory rate (RR), and tidal volumes (V_T)] that would benefit any physiology class. Relative VO_2 represents a standard metric for comparing fitness and predicting performance across individuals as it incorporates body mass, which often penalizes larger individuals, especially those with more body fat (Pescatello, 2014). Adding RR and V_T provides an opportunity for students to perform a simple calculation and dimensional analysis to determine VE.

Adding VCO_2 would allow students to calculate RER (RER = $VCO_2 \div VO_2$). Discussing RER could be challenging in this context because VO_2 kinetics are faster than VCO_2 kinetics (Hughson & Morrissey, 1982; Whipp et al., 1982). Therefore, RER may not or only slightly exceed 1.0 in such a short event, even with the near-exclusive use of carbohydrates. Despite the difficulty of obtaining better blood pH and lactate levels as explained below, the drop in blood pH and increase in $[BLa^-]$ remain key causes and indicators of peripheral fatigue, respectively, for even introductory anatomy & physiology classes.

Especially with new variables, this activity also helps students discover some variables we use to predict and compare fitness. For example, Runner One, despite a lower absolute VO_2, has a higher relative VO_2. Runner One's VE and $[BLa^-]$ rise but to lower values than Runner Two's, while their blood pH drops but by a smaller degree. Together, this shows how Runner One has better cardiorespiratory fitness as their relative VO_2 is higher while they simultaneously expend less energy ventilating and rely less on anaerobic metabolism.

Despite improvements with the new data, this activity could improve with additional data. Recruiting both a highly-trained endurance athlete and someone with average fitness would better reflect the scenario shown in Appendices 2 and 3 and minimize the need to reshape the data or make predictions based on published literature. Collecting this data with a portable metabolic cart would eliminate the risk of running at high speeds on a treadmill until exhaustion and would incorporate more realistic pacing: the last 100 meters of a maximal effort 400m is likely always the slowest. Measuring $[BLa^-]$ and stroke volume are impractical during

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400m dash on a track. Nevertheless, stroke volume and cardiac output could also be non-invasively estimated if participants also performed a VO_2 max test (Burchert & Klimpel, 2023). Adding MVC data via twitch interpolation to assess central fatigue is possible but may not be worth adding given that peripheral fatigue is the primary fatigue mechanism in a 400m dash.

This revised activity more accurately highlights the contribution of peripheral fatigue during a 400m dash. The revisions introduce real-world physiological data and that from peer-reviewed literature to better match the expected exercise intensity domain of the two runners. This remains suitable for introductory physiology classes at multiple levels and can be extended to exercise physiology classes, especially if future additions include more real-world data.

Summary and Conclusion

This activity revises a previous exercise that correctly communicated several important contributions to muscle fatigue. Although the updated data has limitations, it better approximates real-world responses to exercise in the severe and extreme intensity domains. With the revised data we offer two versions of the activity: one version for an entry-level physiology course and the other for an upper-level physiology or exercise physiology course. Finally, there is room for exercise physiology classes to further expand on this activity as instructors could introduce the nuances of oxygen and carbon dioxide kinetics and the delay in the appearance of blood lactate, especially in response to near-maximal exercise.

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Appendix 1. Aerobic Fitness During a 400 Meter Dash

Instructor's Version

Why?

Some people can run a long way and not look tired, and others run a short distance and look exhausted. What's the difference? This activity is an introduction to exercise and the physiology of fitness.

Model 1: Read Graphic Novel—400 Meter Dash (Last page)

Questions

1. One lap of the track is 400 meters (m). Who ran 400 m in less time: the male or the female?

   Female.

2. Describe the physical states of the two individuals at the end of the race.
   How do they look?

   The female: *Looks good, little fatigue. Good posture, no labored breathing.*

   The male: *Lots of fatigue or stress. Labored breathing, sweating, poor posture.*

3. Could the female have completed the race in a shorter amount of time?

   Explain: *Probably. It looks like she could run faster because she does not look fatigued.*

   Could the male have completed the race in a shorter amount of time?

   Explain: *Probably not. Looks like he's totally exhausted and has put forth his maximum effort.*

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4. Predict (guess) how the following variables changed (increased, decreased, or stayed the same) in the male between the beginning of the race and the end of the race. Do not fill in the fourth column (Actual Change) yet. Manager: Encourage individual group members to take turns making predictions, and do not spend more than 3 minutes on this question.

Variable	Units	Predicted Change (increase, decrease, stay the same)	Actual Change (increase, decrease, stay the same) (Do not fill in this section until directed to do so.)
Blood lactate (an indicator of rapid ATP production from glucose)	mmole/L	*Predictions go here.*	*Increases* *(Note: reporting for the male runner, only)*
Oxygen consumption	L/minute	*Predictions go here.*	*Increases*
Arterial hemoglobin saturation (a measure of oxygen availability)	%	*Predictions go here.*	*Stays the same*
Heart rate	beats/minute	*Predictions go here.*	*Increases for the male*
Stroke volume	ml of blood pumped/ beat	*Predictions go here.*	*Increases and decreases*
Blood pH	No units	*Predictions go here.*	*Decreases*
Blood glucose	mg/dL	*Predictions go here.*	*Increases*
Ventilation	L/minute	*Predictions go here.*	*Increases*

5. Based on your predictions, come up with at least one hypothesis as to which variable(s) might be responsible for the male's exhaustion.

Example: I think that he felt tired because he ran out of blood glucose.

Student answers will depend on their predictions.

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Model 2: Physiological Data for the Two Athletes During the 400-Meter Run

The following data represent metabolic conditions in both the male and female runner before, during, and after the race. Arterial Hemoglobin Saturation is the percentage of the total binding sites on hemoglobin molecules, within the red blood cells in the arteries, occupied by oxygen molecules. It is a measure of the oxygen available for body cells. Stroke volume is how much blood pumped by the left ventricle in one beat. Lactate is a molecule involved in energy generation pathways.

Female_400m_run				Arterial					
FEMALE		Blood	Oxygen	Hemoglobin		Stroke	Blood	Blood	
Laps Run	Splits	lactate	Consumption	Saturation	Heart Rate	Volume	pH	glucose	Ventilation
	seconds	mmole / L	Liters / minute	%	Beats / Min	ml / beat		mg / dL	L / min
1_min_Pre_race		0.89	0.25	99%	60	75	7.5	93	7
0.250	19	1.23	2.40	99%	100	95	7.5	94	70
0.500	21	3.61	2.52	99%	130	110	7.4	96	75
0.750	23	4.23	2.51	99%	135	120	7.4	99	80
1.000	19	5.10	2.62	99%	136	125	7.3	101	82
Total time	82								
Male_400m_run				Arterial					
MALE			Oxygen	Hemoglobin		Stroke	Blood	Blood	
Laps Run	Splits	Blood_lactate	Consumption	Saturation	Heart Rate	Volume	pH	glucose	Ventilation
	seconds	mmole / L	Liters / minute	%	Beats / Min	ml / beat		mg / dL	L / min
1_min_Pre_race		1.10	0.50	99%	70	85	7.5	100	15
0.250	19	3.10	2.36	99%	119	110	7.4	100	65
0.500	21	6.80	2.61	99%	158	119	7.3	101	68
0.750	23	13.90	2.82	99%	170	105	7.2	101	70
1.000	20	20.00	3.00	99%	185	92	7.0	102	71
Total time	83								

Critical Thinking Questions

6. Use a blank piece of paper and make rough graphs of each of the variables in Model 2. (Note: slope of the line is the key component.) Be sure to include the data that were collected 1-minute prior to the race. Split-up this task between group members and make sure that you include the male and female data on the same graph.

Graphs on separate sheet. Instructors can provide students with some of the graphs in order to save time.

7. As a group, identify two or three variables that show big differences between the male and female runner.

Blood lactate is the largest, but others, such as heart rate and blood pH also show differences.

Remember that pH is a logarithmic scale, so that difference is quite large.

8. As a group, choose two or three variables that you could use to determine which individual is in better shape: the male or the female.

Answers will vary but should match answers to Question 7. Blood lactate, stroke volume, and blood pH will likely be common predictions.

9. Use your graphs to fill in the right-hand column of the table in Question 4, comparing the level of each variable at the beginning of the race and the end of the race for the male only.

Students put answers in the table. Teacher's note–use only the male's data.

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10. The male is blaming his exhaustion on the lack of oxygen. Does the data set in Model 2 support his statement? You may be asked to defend your answer to the class, so make sure that your spokesperson can explain the group's reasoning.

No, because his hemoglobin saturation level is unchanged.

11. Surprisingly, scientists disagree about what actually causes fatigue. In your group, discuss whether or not each of the following changes is a likely cause of muscle fatigue, and develop a complete sentence for each explaining your answers.

Increased blood glucose

Answers will vary. Probably not; both showed similar levels of blood glucose, and glucose is fuel for working muscles.

Increased heart rate

Students could reason that this is a cause of fatigue, since the male had a much greater increase in heart rate. Theoretically, though, this is not a likely hypothesis. Increased heart rate is more likely to be CORRELATED with fatigue than CAUSAL. Students could also reason that increased heart rate would increase blood delivery to muscles so might help prevent fatigue.

Decreased blood pH

This is a common answer for exercise physiologists and represents a good prediction. However, new understanding of exercise physiology indicates other factors such as temperature change and even reduced signaling from the central nervous system.

Extension Question

12. Which of the changes observed in the athletes would increase delivery of oxygen and glucose to exercising muscles? In other words, which of the changes represent helpful responses to the demands of exercise?

Increased ventilation, heart rate, stroke volume, blood glucose.

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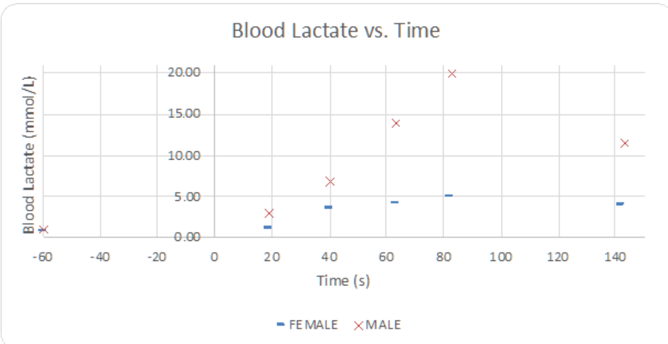
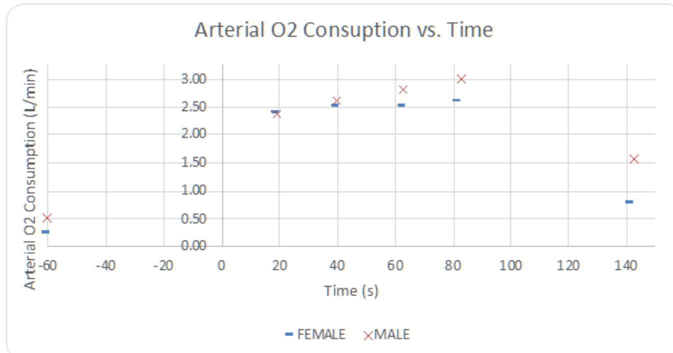
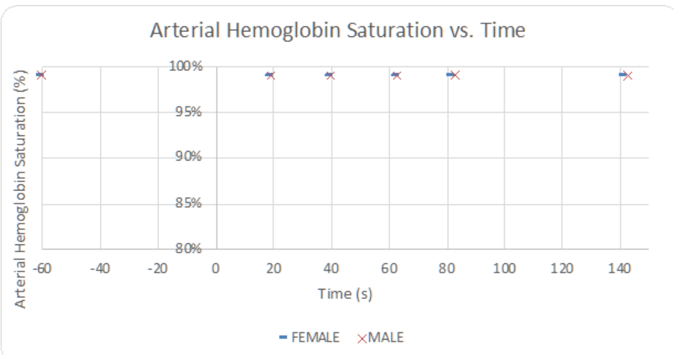
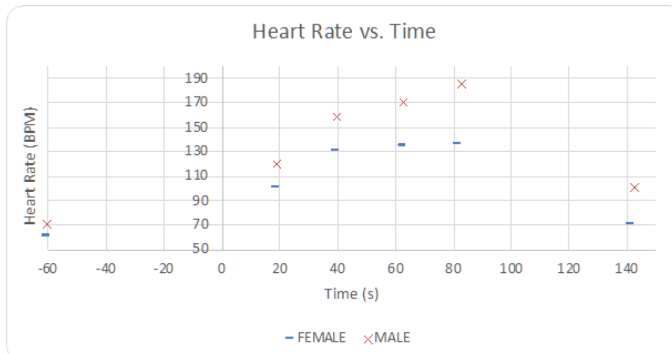
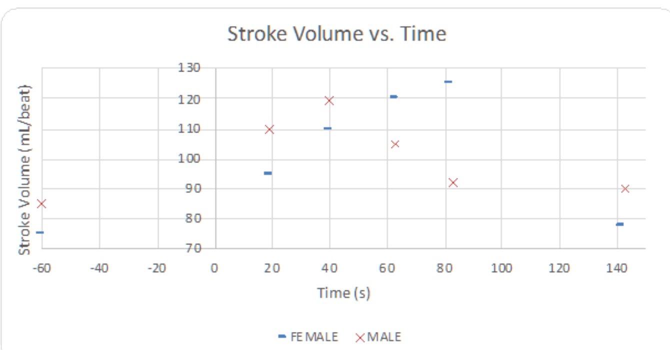
Graphs:

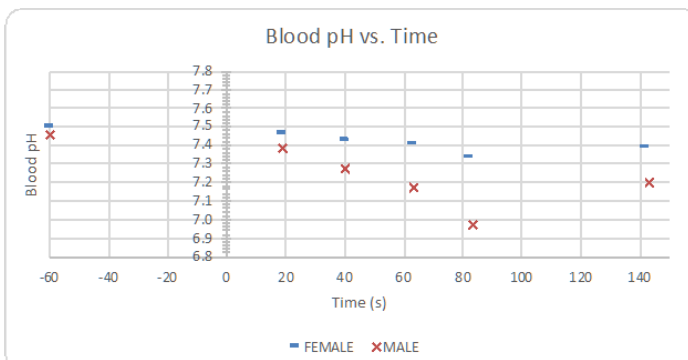


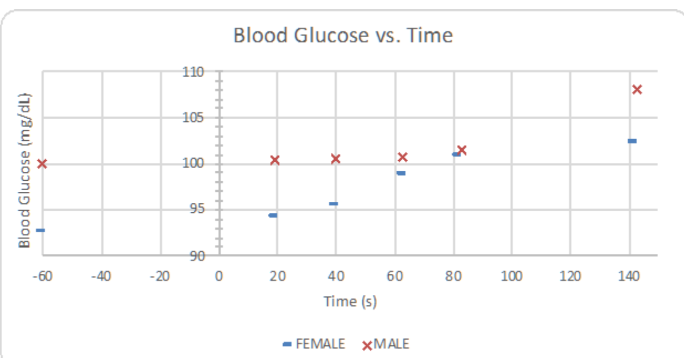


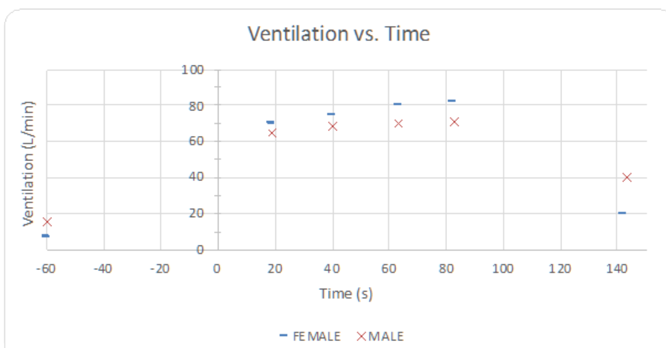












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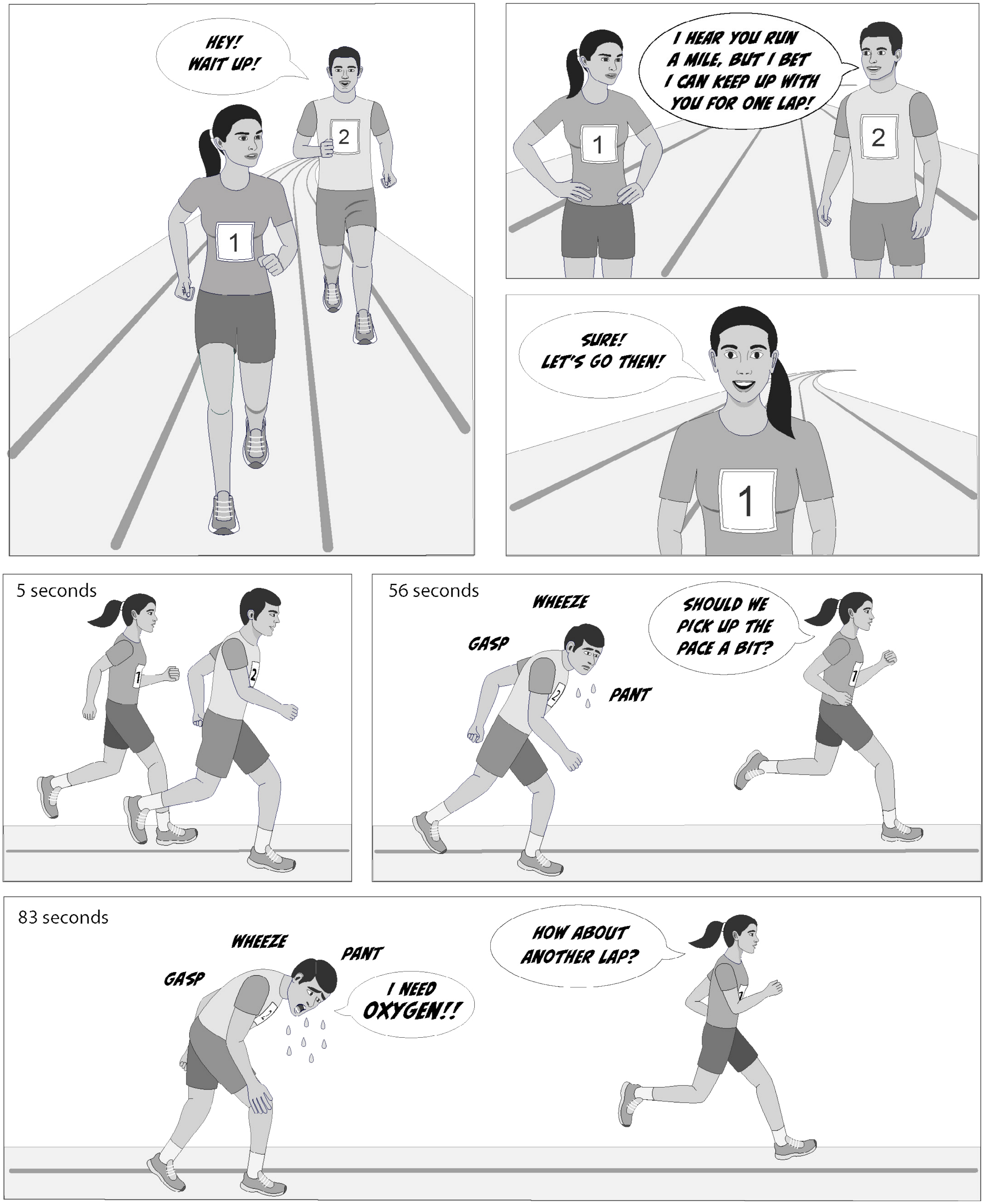
400 Meter Dash



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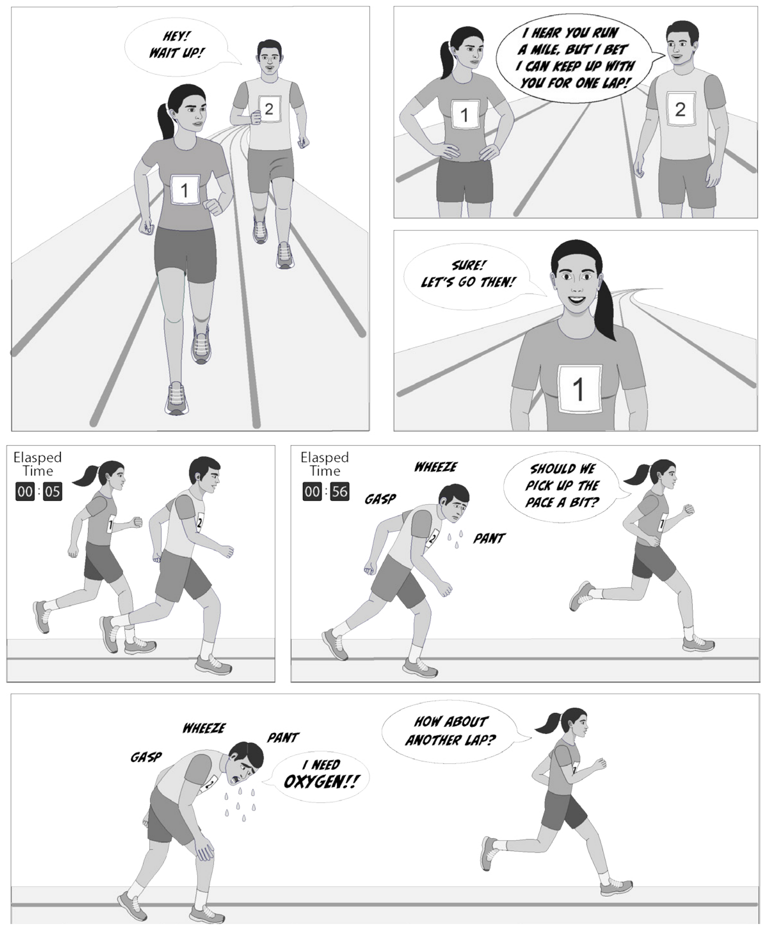
Appendix 2. Aerobic Fitness During a 400 Meter Dash

Biol 1015

Why?

Some people can run a long way and not look tired, and others run a short distance and look exhausted. What's the difference? This activity is an introduction to exercise and the physiology of fitness.

Model 1: Read Graphic Novel—400 Meter Dash



Questions

1. Have a member of your group read, expressively, the text in the above graphic novel. Runner 1 completed the 400 meters in 74 seconds ("1 minute 14 seconds). On the last panel of the graphic, draw a "finish line" under the front foot of Runner 1 and write "1 minute 14 seconds" in the frame to mark the end time of the run.

2. Who ran 400 meters in less time: Runner 1 or Runner 2?

3. Looking at the graphic novel, describe the physical states of the two individuals at the end of the race. How do they look?

Runner 1:

Runner 2:

continued on next page

4. Could Runner 1 have completed the race in a shorter amount of time?

Explain:

Could Runner 2 have completed the race in a shorter amount of time?

Explain:

Table 1: Data related to the two runners during the 400-meter run.

Use this information to answer Question 4.

Athlete	Body Mass (kg)	Time (s)	Distance (m)	Absolute Oxygen Consumption (VO2) (L/min)	Carbon Dioxide Production (VCO2) (L/min)	Respiratory Rate (Breaths/min)	Tidal Volume (mL/breath)	Arterial Hemoglobin Saturation (SaO2) (%)	Heart Rate (Beats/min)	Stroke Volume (mL/beat)	Blood Lactate (mmol/L)	Blood pH	Blood Glucose (mL/dL)
Runner 1	59	0	0	0.49	0.62	16	904	99	125	76	2.1	7.40	99
		19	100	1.43	1.98	25	1382	99	147	89	3.1	7.38	99
		38	200	2.37	2.41	32	2160	99	158	103	4.0	7.36	99
		56	300	2.82	2.48	37	2256	99	166	110	5.0	7.33	100
		74	400	3.01	2.55	41	2284	99	171	118	5.9	7.31	100
Runner 2	85	0	0	0.64	0.78	14	1584	99	141	85	2.4	7.39	100
		19	100	1.29	1.82	23	2507	99	151	110	3.7	7.33	100
		38	200	2.06	2.21	27	2748	99	169	120	4.9	7.27	101
		56	300	3.21	2.72	33	2957	99	178	123	6.2	7.20	101
		75	400	3.48	3.03	38	2965	99	182	120	7.4	7.14	102

Note: a larger version of Table 1 can be found on the page following the graphic novel.

5. Use the information in Table 1 above to fill in the chart below. Specifically, in the first column, write the units used for each variable. In the second column attempt to define the variables. (The first one is done for you.) If you cannot guess anything, simply write "no idea." In the third and fourth columns, write the data trend (steady, up, up significantly, down, down significantly) for each variable and for each runner over the duration of the race.

Variable	Units	Meaning	Runner 1 Trend	Runner 2 Trend
Blood Glucose	mg/dL	Amount (quantity) of glucose in the blood.	Slightly up	Slightly up
Heart Rate				
Blood pH				
Ventilation L/min				
Respiratory Rate				
Arterial Hemoglobin Saturation (SaO2)				
Blood Lactate				
Tidal Volume				
Stroke Volume				
Absolute Oxygen Consumption (VO2)				
Carbon Dioxide Production (VCO2)				

continued on next page

6. Two additional variables frequently used by exercise physiologist are derived from the above data. First, the **Respiratory Exchange Ratio (RER)** is calculated by dividing VCO2 by VO2. The second is **Relative Oxygen Consumption**, which is calculated by dividing Absolute Oxygen Consumption by body weight. Note that units for Absolute Oxygen Consumption is liters / minute (L/min) whereas the units for Relative Oxygen Consumption units are milliliters / kilogram / minute (ml/kg/min). Adjust your calculations accordingly.

Using the data below, calculate the RER and Relative VO2 max for each individual.

Calculate the Respiratory Exchange Ratios

Athlete	Carbon Dioxide Production (VCO2) (L/min)	Absolute Oxygen Consumption (VO2) (L/min)	Respiratory Exchange Ratio (RER)
Runner 1	0.62	0.49	1.3
	1.98	1.43	
	2.41	2.37	
	2.48	2.82	
	2.55	3.01	
Runner 2	0.78	0.64	
	1.82	1.29	
	2.21	2.06	
	2.72	3.21	
	3.03	3.48	

Calculate the Relative Oxygen Consumption

Athlete	Body Mass (kg)	Absolute Oxygen Consumption (L/min)	Relative Oxygen Consumption (ml/kg/min)
Runner 1	59	0.49 L/min	8.3 ml/kg/min
		1.43	
		2.37	
		2.82	
		3.01	
Runner 2	85	0.64	
		1.29	
		2.06	
		3.21	
		3.48	

continued on next page

7. RER and Relative Oxygen Consumption are two examples of derived data used in exercise physiology. As a group, develop a new, novel, variable that your team thinks is a descriptive data point to measure an athletes overall fitness. (Hint: one data point that combines two or more existing variables found in Table 1.)

8. Runner 2 is blaming his exhaustion on the lack of oxygen. Does the data set in Model 2 support his statement?

9. As a group, develop a hypothesis as to which variable(s) might be most responsible for the male's exhaustion.

Extension question:

10. Exercise physiologists use the terms moderate, heavy, and severe to classify different levels of physical effort. As a team, use the variables above to develop definitions or descriptions for each domain.

Moderate Exercise

Heavy Exercise

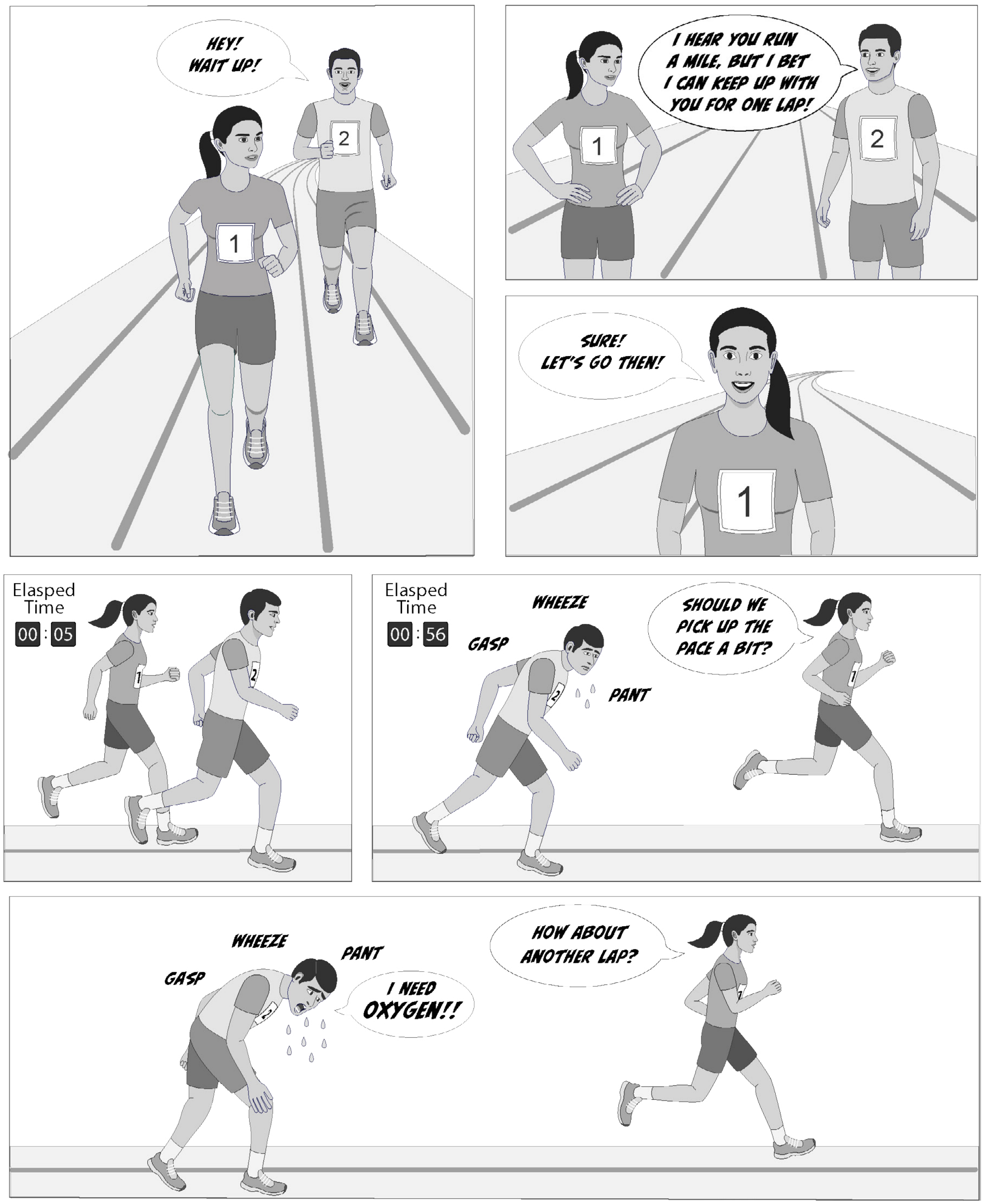
Severe Exercise

continued on next page

Appendix 3. Aerobic Fitness During a 400-Meter Dash

Some people can run a long way and not look tired, and others run a short distance and look exhausted. What's the difference? This activity is an introduction to exercise and the physiology of fitness.

Model 1: Read the Graphic Novel—400 Meter Dash. You can also see [this video] to see what Model 1 may have looked like in real life (the video is for illustration only and is not part of Model 1).



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Questions

1. One lap of the track is 400 meters (m). Who ran 400 m in less time: Runner 1 or Runner 2?

2. Looking at the graphic novel, describe the physical states of the two individuals at the end of the race. How do they look?
    a. Runner 1

    b. Runner 2

3. Considering their physical states at the end of the race:
    a. Could Runner 1 have completed the race in a shorter amount of time? Explain.

    b. Could Runner 2 have completed the race in a shorter amount of time? Explain.

continued on next page

4. Predict (guess) how the following variables changed (increased, decreased, or stayed the same) in Runner 1 between the beginning and the end of the race by filling in the 3rd column. Do NOT fill in the fourth column (Actual Change) yet. **Manager**: Encourage individual group members to take turns making predictions, and do not spend more than 3 minutes on this question.

Variable	Units	**Predicted Change** (increase, decrease, stay the same)	**Actual Change** (increase, decrease, stay the same) (Do not fill in this section until directed)
Blood lactate ([BLa$^-$]) (an indicator of rapid ATP production from glucose)	mmol/L		
Blood pH	No units		
Oxygen consumption	L/minute		
Arterial hemoglobin saturation (a measure of oxygen availability)	%		
Heart rate	beats / minute		
Stroke volume	mL of blood pumped / beat		
Blood glucose	mg / dL		
Tidal volume	mL / breath		
Respiratory rate	breaths / minute		

Absolute oxygen consumption (VO_2): the body's oxygen consumption rate, expressed in mL/min or L/min.

Arterial hemoglobin saturation (SaO_2): the percentage of the total binding sites on hemoglobin molecules within the red blood cells in the arteries that are occupied by oxygen molecules, expressed in percent (%).

Blood lactate: the concentration of lactate molecules in the blood, expressed in mmol/L.

Blood pH: the measure of acidity/alkalinity of the blood. Note: pH is unitless.

Blood glucose: the concentration of glucose molecules found in a deciliter of blood, expressed in mL/dL.

Carbon dioxide production (VCO_2): the body's carbon dioxide production rate, expressed in mL/min or L/min.

Heart rate: the number of times the heart contracts and relaxes in one minute, expressed in beats per minute.

Respiratory rate: the frequency at which someone breathes over a given time period, usually expressed in breaths/min.

Stroke volume: the volume of blood ejected by the left ventricles during systolic cardiac contraction (for simplicity, one heartbeat), expressed in mL/beat

Tidal volume: the volume of air inhaled or exhaled in a single breath, expressed in mL/breath

5. Based on your predictions, come up with at least one hypothesis as to which variable(s) might be responsible or best explain Runner 2's exhaustion.

continued on next page

Model 2: Physiological Data for the Two Athletes During the 400-Meter Dash

The following data represent metabolic conditions in both Runners 1 and 2 before, during, and after the race. See variable definitions underneath the prediction table shown with the Model 1 questions.

Athlete	Body Mass (kg)	Time (s)	Distance (m)	Absolute Oxygen Consumption (VO2) (L/min)	Carbon Dioxide Production (VCO2) (L/min)	Respiratory Rate (Breaths/ min)	Tidal Volume (mL/ breath)	Arterial Hemoglobin Saturation (SaO2) (%)	Heart Rate (Beats / min)	Stroke Volume (mL/beat)	Blood Lactate (mmol/L)	Blood pH	Blood Glucose (mL/dL)
Runner 1	59	0	0	0.49	0.62	16	904	99	125	76.0	2.1	7.40	99
		19	100	1.43	1.98	25	1382	99	147	89.0	3.1	7.38	99
		38	200	2.37	2.41	32	2160	99	158	103.0	4.0	7.36	99
		56	300	2.82	2.48	37	2256	99	166	110.0	5.0	7.33	100
		74	400	3.01	2.55	41	2284	99	171	118.0	5.9	7.31	100
Runner 2	85	0	0	0.64	0.78	14	1584	99	141	85.0	2.4	7.39	100
		19	100	1.29	1.82	23	2507	99	151	110.0	3.7	7.33	100
		38	200	2.06	2.21	27	2748	99	169	120.0	4.9	7.27	101
		56	300	3.21	2.72	33	2957	99	178	123.0	6.2	7.20	101
		75	400	3.48	3.03	38	2965	99	182	120	7.4	7.14	102

Questions

6. Using the data in Model 1, create new columns for and calculate the following variables. You can do this by hand or by downloading or creating a copy of the Model 1 spreadsheet and using spreadsheet formulas. Hint: how can you use the units of the variables shown in Model 1 to help you correctly calculate these new variables?

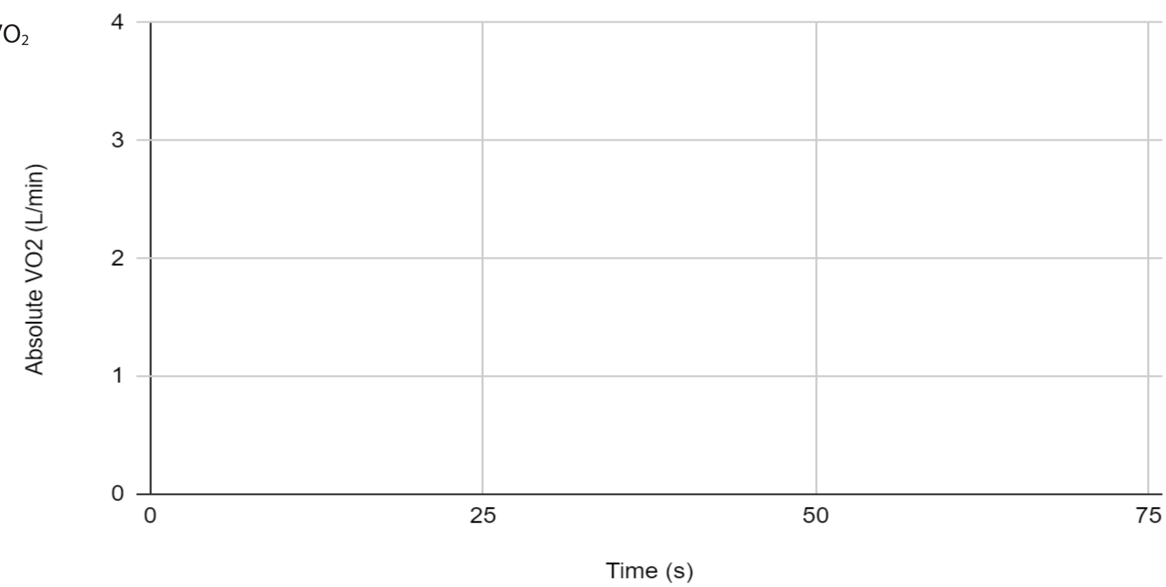
a. **Relative VO_2**: oxygen consumption relative to body mass, expressed in mL/kg/min.

b. **Minute ventilation**: the total volume of air ventilated in or out of the lungs per minute, expressed in L/min.

c. **Cardiac output**: the total volume of blood pumped by the heart every minute, expressed in L/min.

7. Using the empty charts below to make rough graphs of the variables listed below. Note: the trends in the data and the comparisons between the two runners are the key takeaways from this question. Be sure to include the data that were prior to the race (time = 0). Split up this task between group members and make sure to include both Runners 1 and 2 on the same graph.

a. Absolute VO_2



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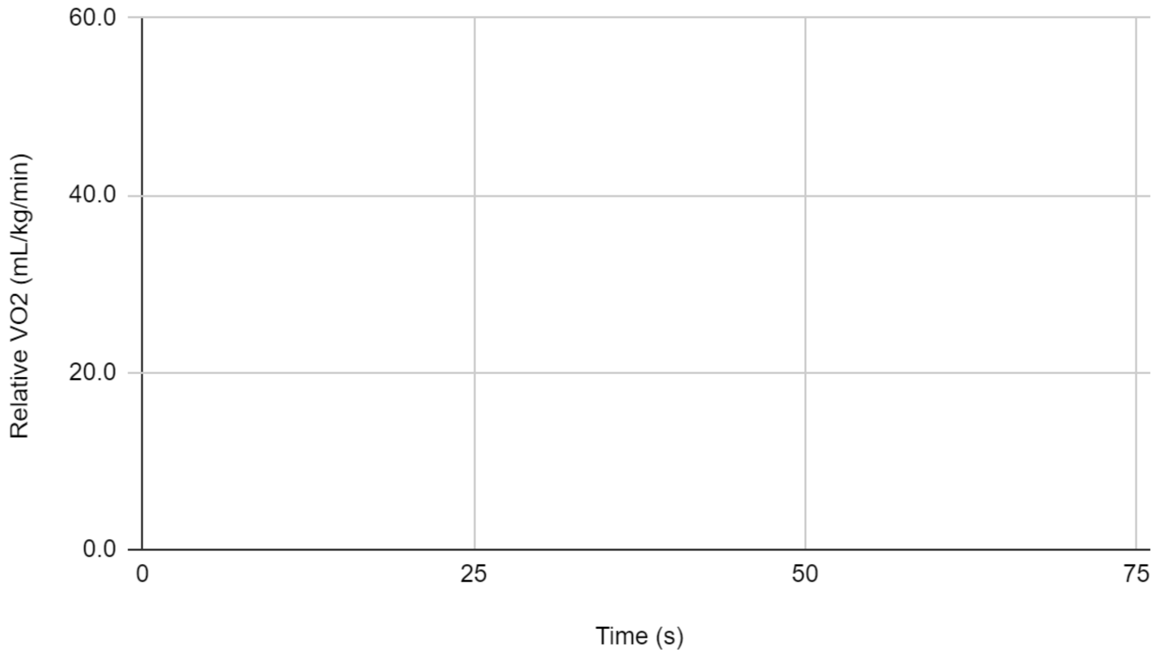
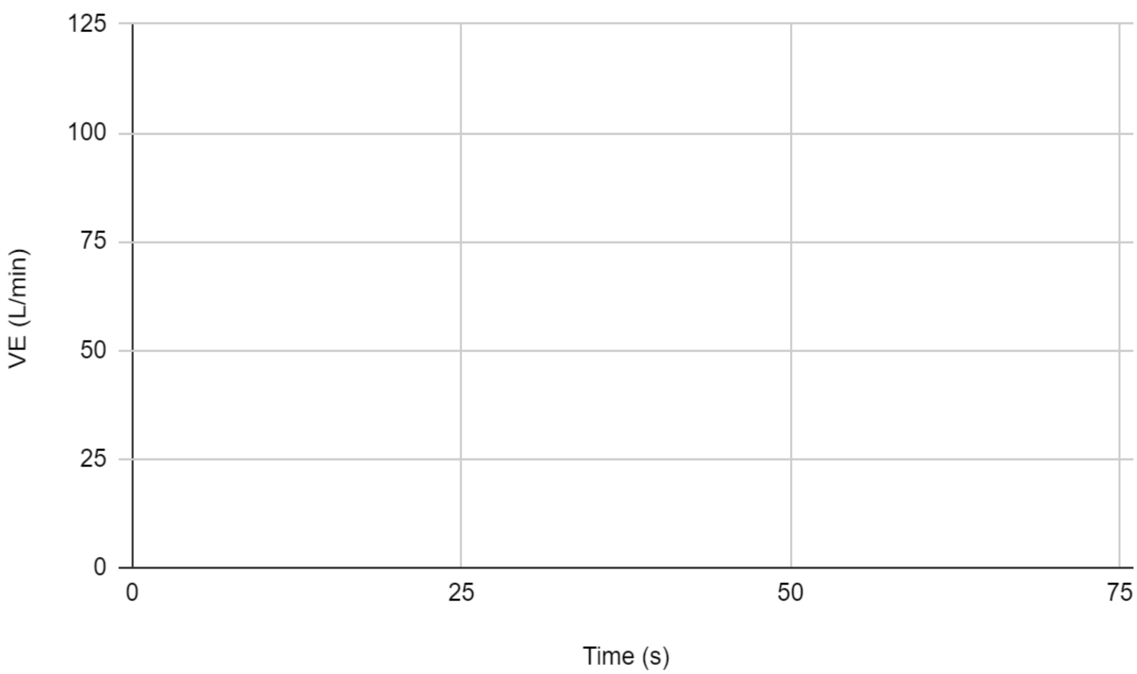
b. Relative VO_2



c. Minute ventilation



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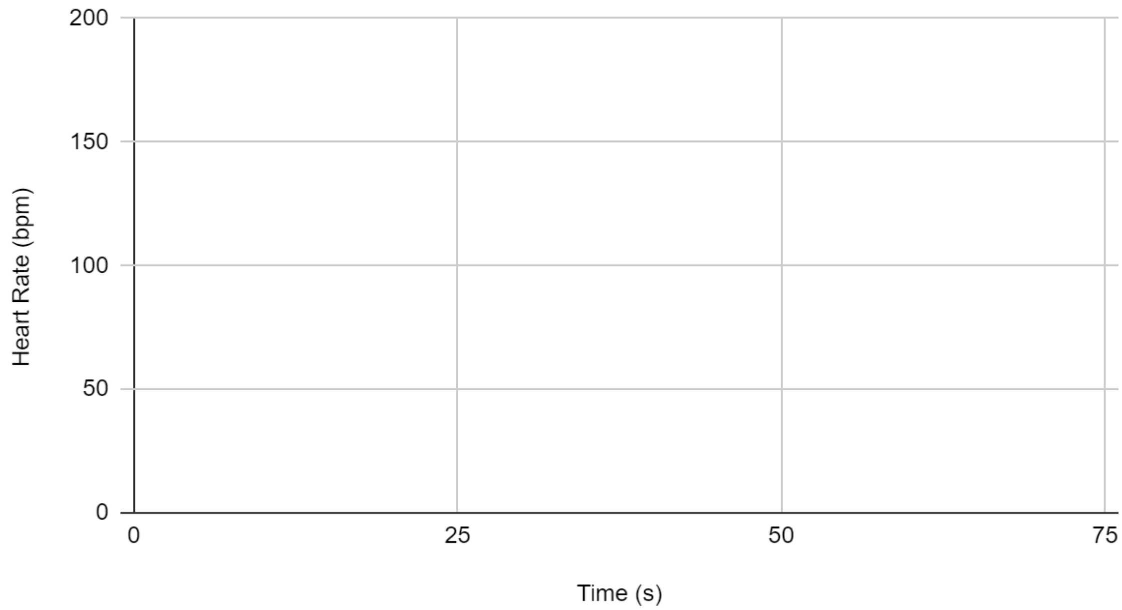
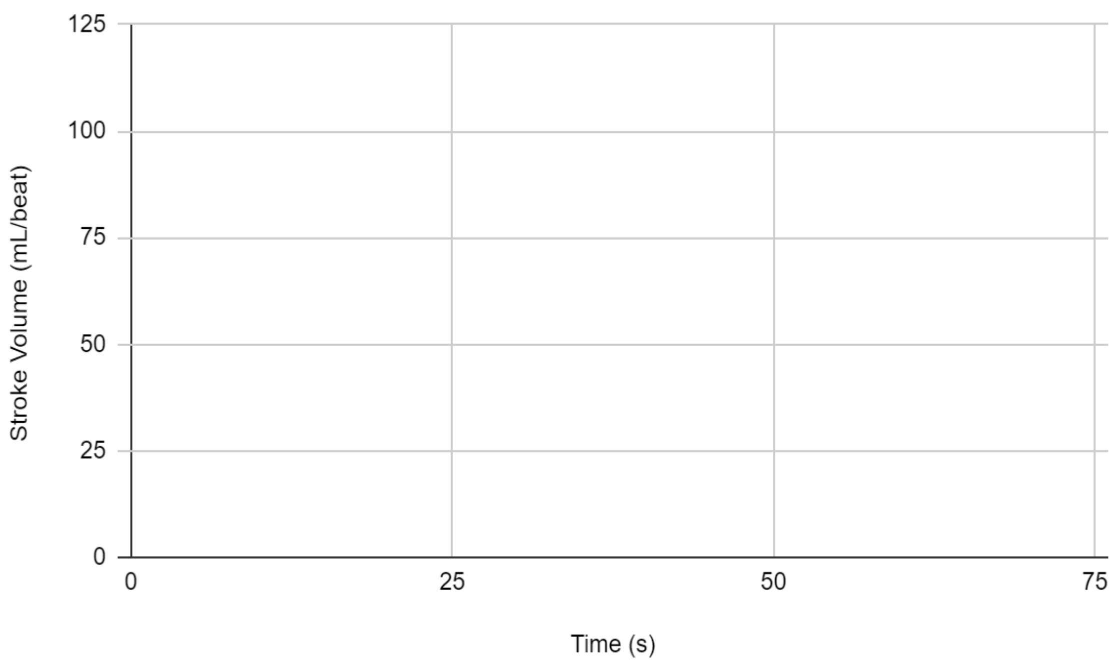
d. Heart rate



e. Stroke volume



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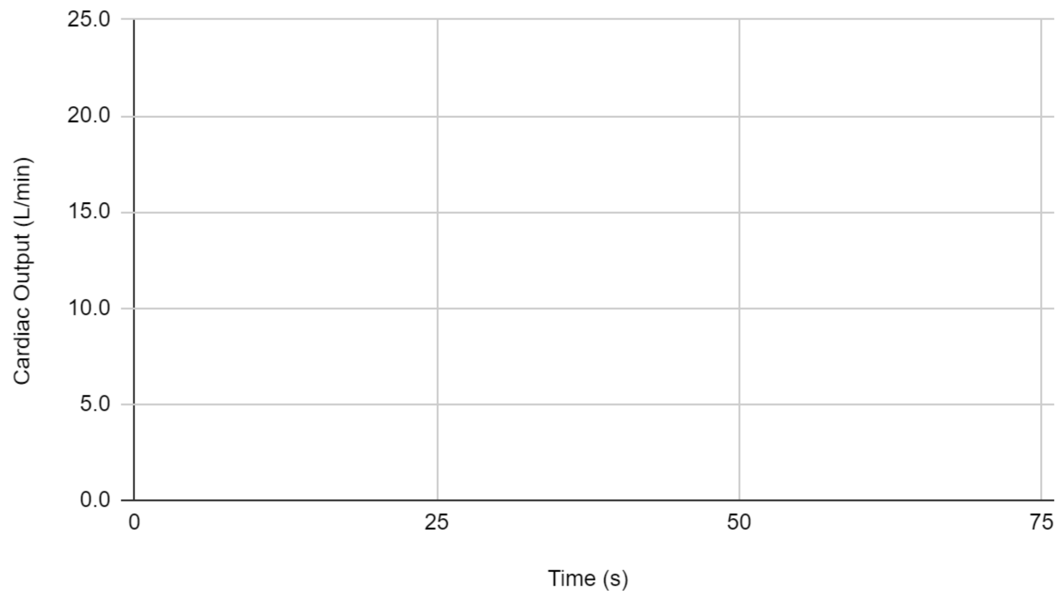
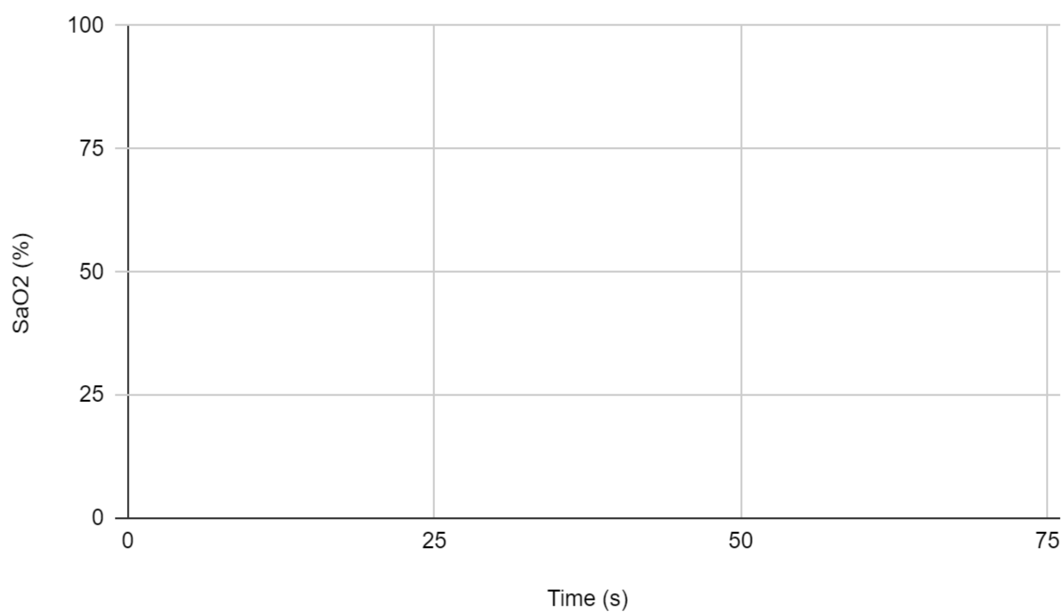
f. Cardiac output



g. SaO_2



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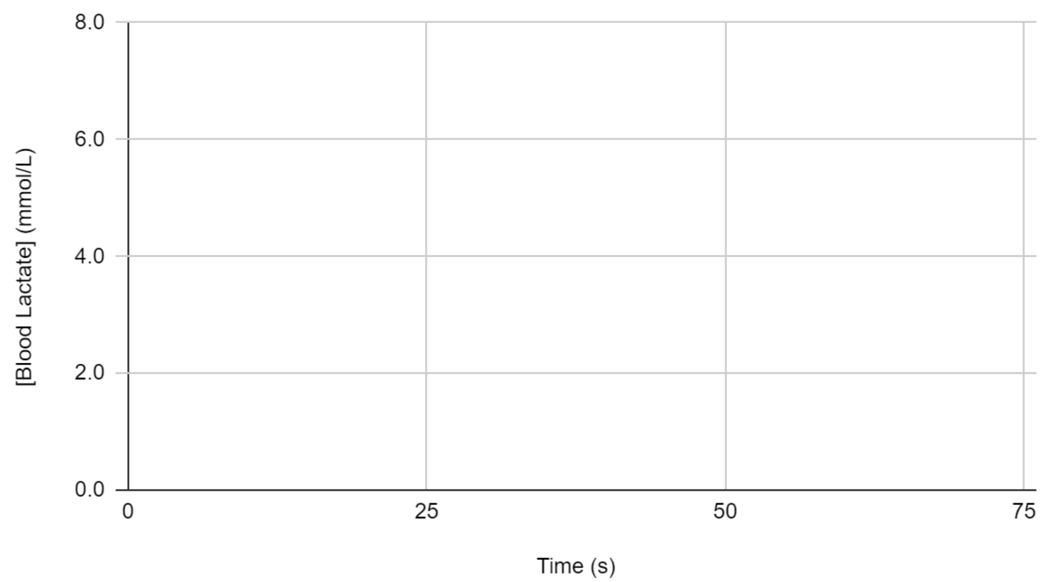
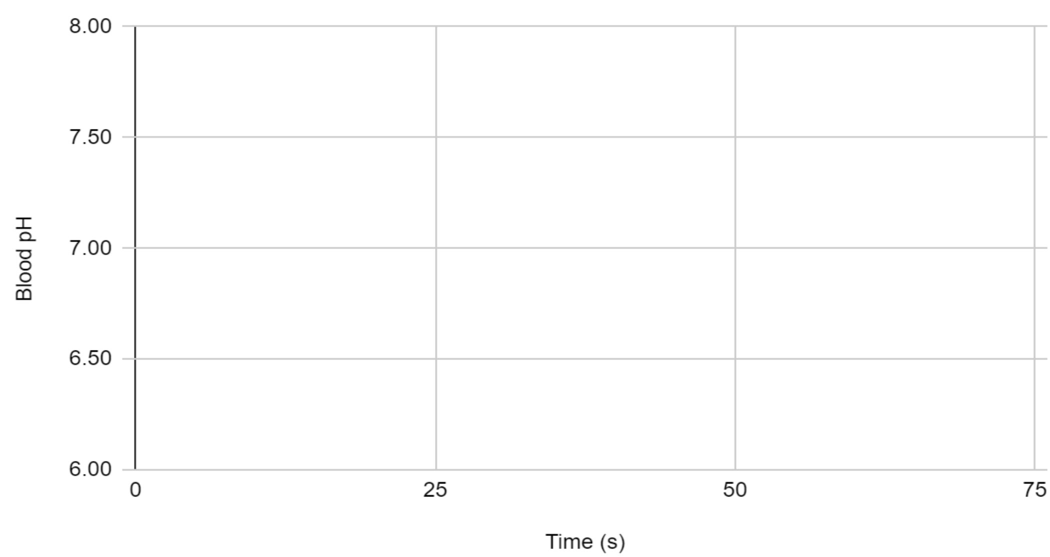
h. Blood lactate concentration



i. Blood pH



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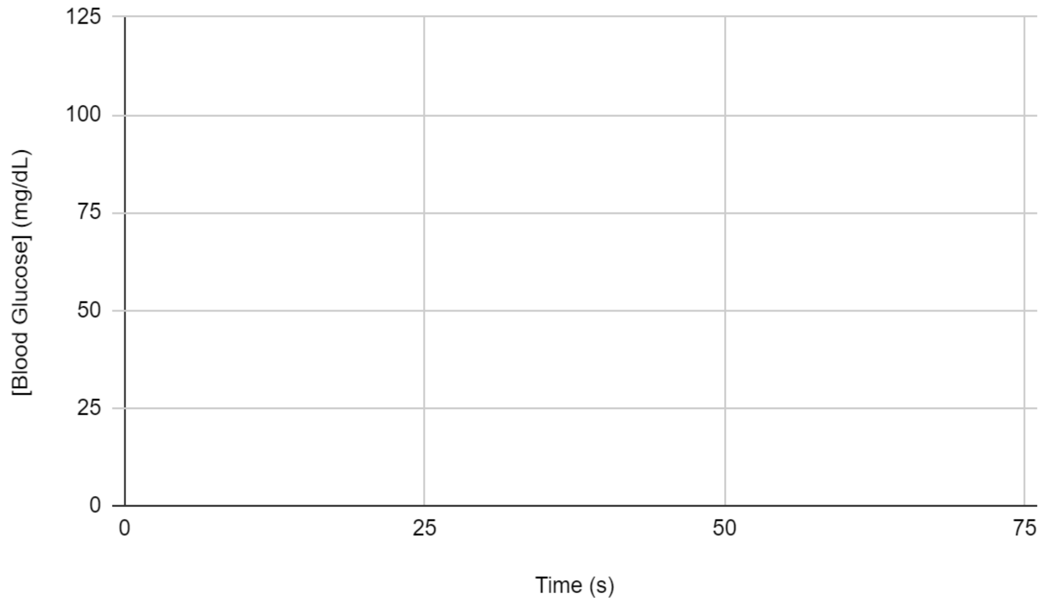
j. Blood glucose



8. As a group, identify two or three variables that show big differences between Runners 1 and 2.

9. As a group, choose two or three variables that you could use to determine which individual is in better shape: Runner 1 or Runner 2.

10. Use your graphs to fill in the right-hand column of the table in Question 4 of Model 1, comparing the level of each variable at the beginning of the race and the end of the race for Runner 2 only. Did the data match your predictions?

11. Runner 2 blames his exhaustion on the lack of oxygen. Does the data set and your graphs in Model 2 support his statement? You may be asked to defend your answer to the class, so make sure that your spokesperson can explain the group's reasoning.

12. Surprisingly, scientists somewhat disagree about what actually causes fatigue. In your group, discuss whether each of the following changes is a likely cause of muscle fatigue, and develop a complete sentence for each explaining your answers.

a. Increased blood glucose

b. Increased heart rate

c. Decreased blood pH

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Extension Questions

13. Which of the changes observed in the athletes would increase the delivery of oxygen and glucose to exercising muscles?

14. Exercise physiologists can calculate VO_2max using absolute (mL/min) or relative (mL/kg/min) VO_2. One of these measures is currently the best-known predictor of cardiovascular mortality risk, while the other is not. In addition, one of these versions better predicts endurance performance (to a point), especially for events lasting two minutes or longer.

a. Based on the data, does absolute or relative VO_2max better represent health and fitness?

b. Predict how absolute and relative VO_2max are related to body size and composition.
That is, how would each of these vary as someone gains or loses both fat or muscle mass?

15. Both Runner 1 and Runner 2's blood lactate concentrations rise during the event, but Runner 2's rises more. Does this data support the common refrain that lactic acid causes fatigue?

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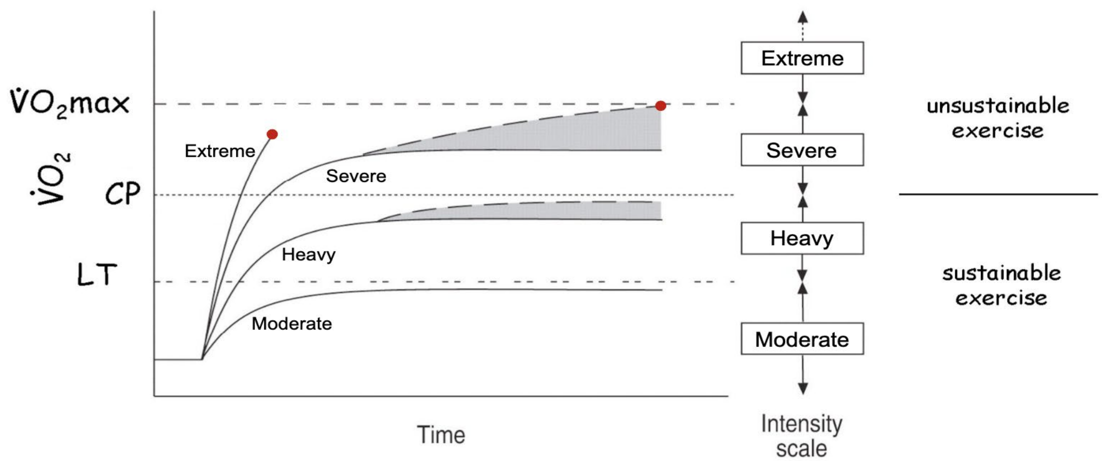
16. One of the best ways to describe cardiovascular exercise intensity is by characteristic VO_2 and [BLa^-] responses. The diagram below depicts the example VO_2 responses to exercise in the different domains.



Each line shows VO_2 responses to constant-intensity exercise in the moderate, heavy, severe, and extreme exercise intensity domains. The red dots represent reaching fatigue. The dashed lines in the heavy and severe domains represent the actual VO_2 response due to the VO_2 slow component. The shaded regions represent the magnitude of the VO_2 slow component, or the extra aerobic energy requirement above a theoretically expected value for a constant exercise intensity (Jamnick et al. 2020). Abbreviations: critical power (CP); (first) lactate threshold (LT). Figure adapted from Ferguson (2020).

a. In which domains can one achieve a “steady-state” VO_2, or a value that remains relatively consistent over time?

b. What separates the different exercise intensity domains?

c. Based on the example VO_2 responses in this figure and data previously presented in this activity, which exercise intensity domains are Runners One and Two working in? Justify your answer.

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Ferguson, S. (2020, September 24). *Understand intensity domains to simplify your training thresholds (Part 2)*. Summation Athletics. https://www.summationathletics.com/blog/understand-intensity-domains-to-simplify-your-training-thresholds-part-2

Jamnick, N. A., Pettitt, R. W., Granata, C., Pyne, D. B., & Bishop, D. J. (2020). An Examination and Critique of Current Methods to Determine Exercise Intensity. *Sports Medicine*, *50*(10), 1729–1756. https://doi.org/10.1007/s40279-020-01322-8

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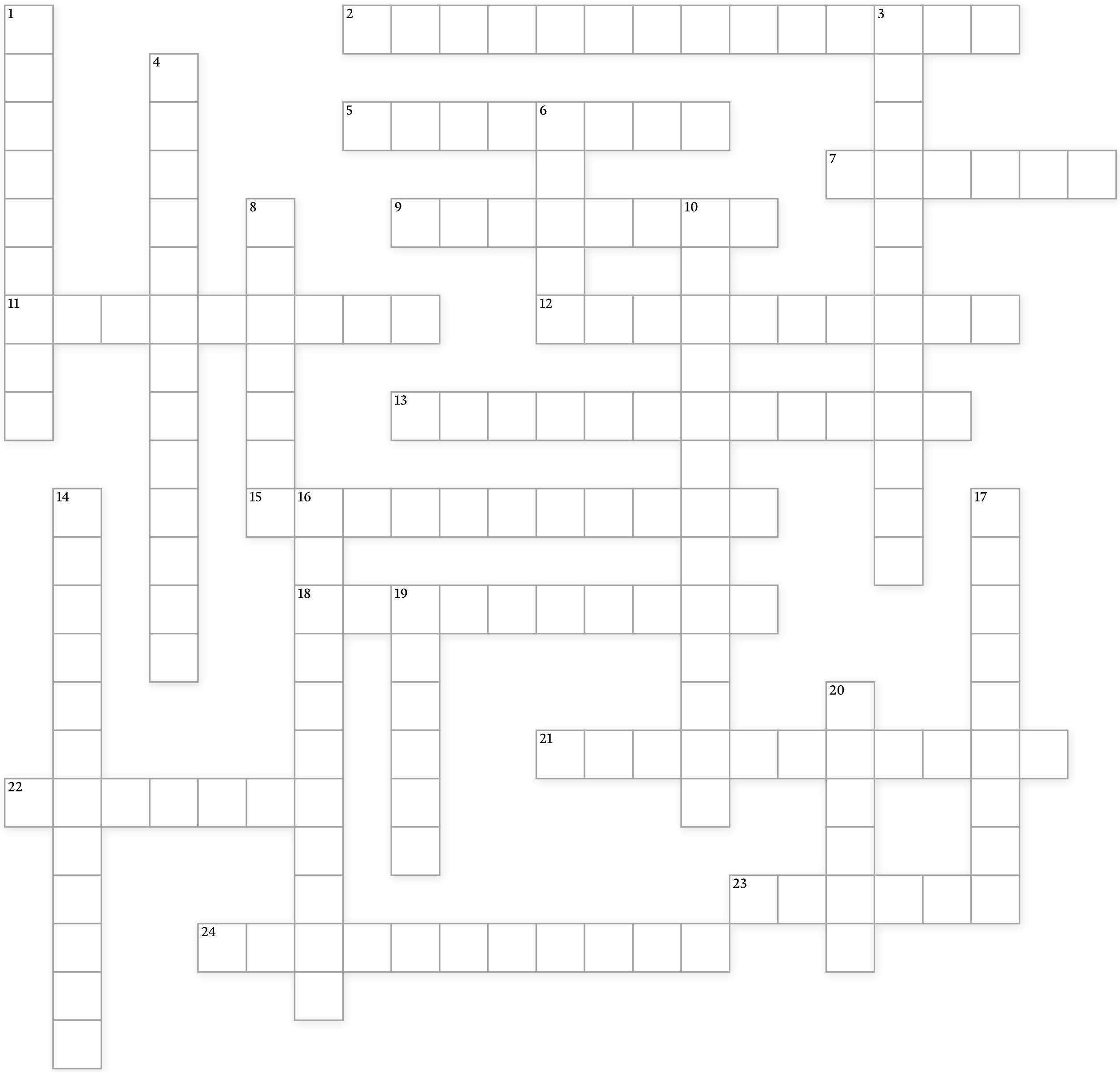
HAPS Educator Crossword 4: The Heart

(For an online version CLICK HERE.)



ACROSS

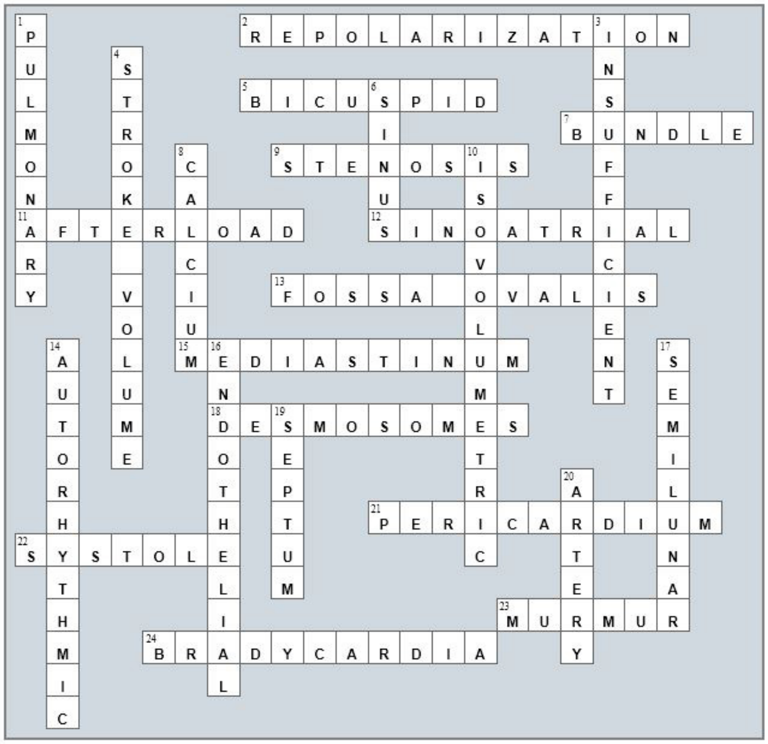
2. In an ECG tracing, the T-wave represents ventricular _____________ .
5. Located between the left atrium and ventricle, the _____________ valve is also called the mitral valve.
7. From the AV node, the action potential next goes to the AV _____________ .
9. Valvular _____________ describes stiff heart valves that do not open completely.
11. Term describing the pressure that the left ventricle has to rise above to open the aortic valve.
12. The pacemaker of the heart located in the right atrium is the ___________ node.
13. After birth, the foramen ovale closes and is now called the _____________ _____________ . (2 words with a space)
15. The heart is located in the _____________ of the thorax.
18. Intercalated discs contain 2 types of junctions: gap junctions and _____________ .
21. The _____________ is the outer layer of the heart.
22. Term that refers to contraction of a ventricle.
23. An abnormal heart sound due to valve issues is called a heart _____________ .
24. Term that refers to a slower than normal heart rate.

DOWN

1. The _____________ circuit carries oxygen-poor blood to the lungs.
3. A heart valve that cannot close completely is said to be _____________ .
4. Cardiac output = heart rate X ____________ ____________ . (2 words separated by a space).
6. Blood from the coronary circulation enters the right atrium via the coronary _____________ .
8. In pacemaker cells, the spike of the action potential is due to voltage-gated _____________ channels.
10. During an _____________ ventricular contraction, ventricular pressure is increasing but the blood is not yet being ejected.
14. Pacemaker cells of the heart contract spontaneously because they are ________.
16. ___________ cells line the heart chambers and the blood vessels.
17. The aortic and pulmonary valves are referred to as ____________ valves.
19. The left and right atria are separated by an interatrial _____________ .
20. Defined as a vessel that carries blood away from the heart.

CLICK HERE for Answer Key

Answer key for: Crossword 4. The Heart (from previous page)



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