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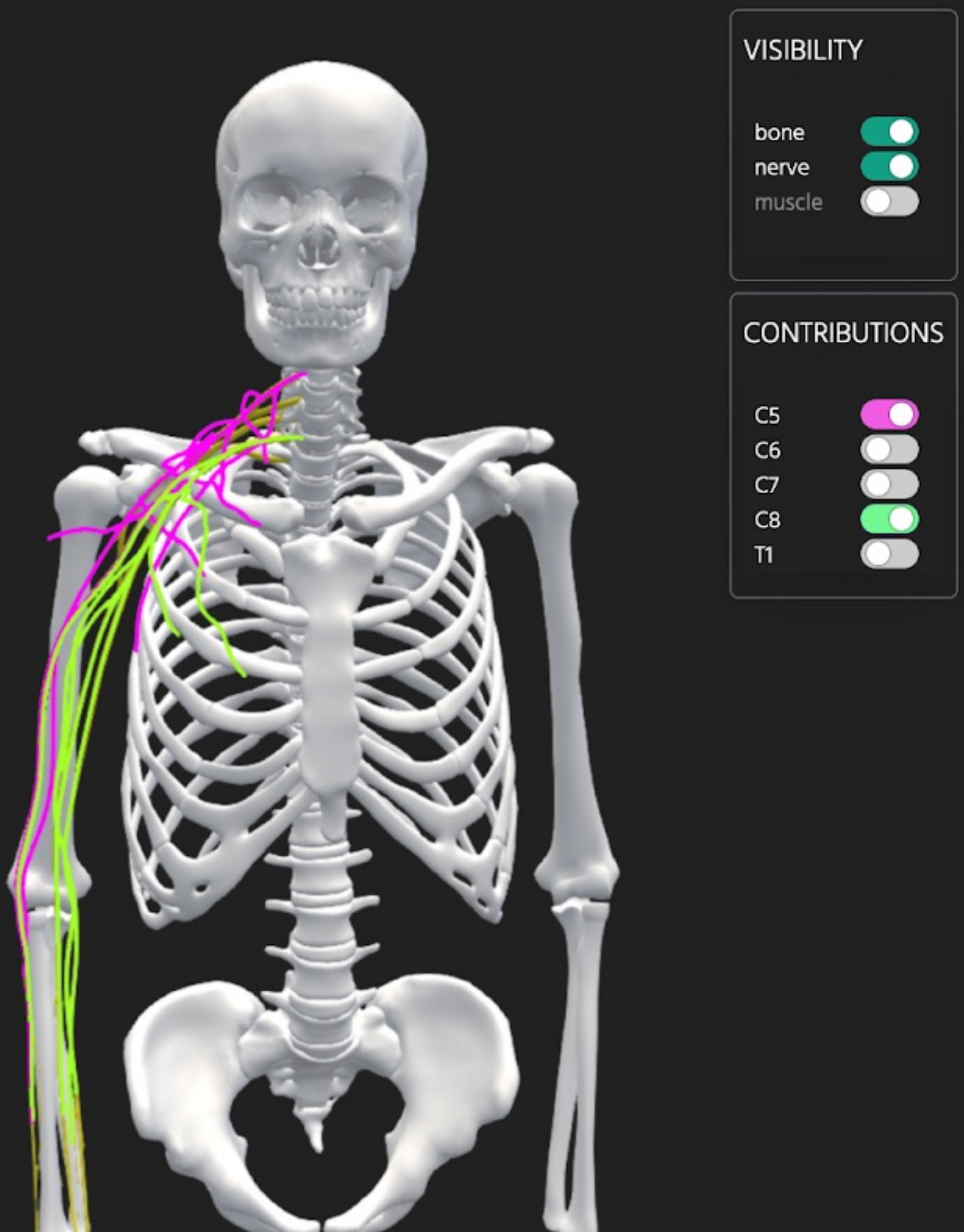

HAPS EDUCATOR JOURNAL

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SUMMER 2026

TABLE OF CONTENTS

HAPS Educator Journal of the Human Anatomy and Physiology Society

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LETTER TO THE EDITOR
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Letter to the Editor: Teaching The Myth of the Average Body

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I have been teaching anatomy and physiology for 13 years and something has shifted in my classroom. During my lecture on the reproductive system, I show students a chart that states the menstrual cycle is 28 days long with ovulation occurring on day 14. More than ever before, there is a palpable collective eyeroll when I show this data, and it is warranted. All anatomy and physiology textbooks select 28 days as a representation of "the average menstrual cycle", but this description of a canonical menstrual cycle is misleading. The actual range of medically defined "healthy" menstrual cycles encompasses 21-35 days (Harvard T. H. Chan School of Public Health, 2026.). Twenty-eight days may be the average for women 30-40 years old, but the average length for college-aged females is closer to 30 days. Even at the individual level, over 50% of women will have variability in their menstrual cycle length month-by-month (Li et al., 2022). So, who does the 28-day average cycle represent? Showcasing the average may function as a reasonable attempt to find compromise amongst the vast array of menstrual cycle lengths, but it inadvertently represents almost no one.

Increasingly I am realizing that differences defined by categorizations, as well as the simplification created by averaging data, are not reflecting my student population or even me. Growing up, whenever I did not see myself represented in the average data or I found myself between categories, I internalized that I was a failed representation of an archetype. I was too fat, too short, not female enough. Compared to earlier years, my current population of students do not seem to be having these same reactions.

I am required to teach sex characteristics that, due to hormones, are on average more prevalent in males or females. Males generally have deeper voices and more body hair. Females are generally shorter. Now more than ever, students ask me questions that challenge these averages, such as "Why do some women have more body hair than others?" and "Why can't I gain muscle mass no matter what I do?". These questions suggest that the classifications of female and male characteristics exist on a spectrum, often with overlap across the sexes. This has always been true but not always discussed aloud. Contemporary students are challenging the content built around an idealized version of the human body, one that few of them recognize.

The discomfort in my classroom echoes a broader truth about how biology organizes the world. The field of biology functions to name, describe, and understand the relationships between all the living organisms on Earth. This work is vitally important. Knowing the similarities and differences between male and female bodies has allowed us to develop potential life-creating medical technologies like in vitro fertilization. Every human being on Earth has benefited from scientific research, but that does not mean there are no limitations in the field.

Fifteen years ago, while earning my Ph.D. in neuroscience, I worked for six years as a graduate research assistant in a neuroendocrinology lab. In our lab we attempted to evaluate sex differences between male and female rat brains. It seemed easy enough: this is a male, this is a female, they are different. In many respects, they were. Males had penises and females had vaginas. Females carried rat pups and nurtured them after birth; male rats did not. Females and males also exhibited different peer social behaviors, mating behaviors, and hormonal release patterns. On average, there were clear differences.

Despite those differences, the reality was that sex differences in the brain were, unsurprising now, but perhaps more surprising then, much more nuanced. There were clear differences in averages across different measurements. Male rats, on average, measured more or less on some parameters compared to female rats. Nonetheless, the range of data had substantial overlap. On some neurological measures that had large average sex differences, the variability in the data showed that the two groups were more similar than different. Within each sex, some females played dramatically more than the average male, and some males showed more anxiety that the average female. Increasing research shows that sex differences in the brain, corresponding to sex differences in behavior, exist in a mosaic pattern (Joel & Vikhanski, 2019). Some males show female patterns and some females show male patterns, and these differences are guided by the complex interplay of genes and environment. Much of this complexity is lost upon publication as overlapping data points create data that does not reach statistical significance, which makes the data less likely to be published. As a result, published stories appear clearer than the data, and that is what makes its way into my lectures.

continued on next page

Fortunately, over time, my student population has started to reject this. I am ecstatic to report that unlike me, who internalized the mismatch between average and personal data as a flaw in my body, my students seem much more likely to blame the data. While this change has benefits and costs, it does mean that this new generation of students will not see themselves as failures when they cannot find themselves reflected in the average.

The comfort my students show in rejecting data that does not reflect them has empowered me as well. I find myself saying in class, "Here is data that reflects almost no one," or "Here is an average produced from studying only 20-year-old men." It feels better for me as an instructor and as a person to prioritize the complexity of humanity over simplified data.

When I teach the female reproductive system now, I explain that while we cannot study every menstrual cycle in detail, the diagram we review is a representative one that is not a true reflection of any individual. I describe the healthy range of cycles and the variability that can occur from month to month (e.g. Bull et al., 2019). I also note that nearly a quarter of women have irregular cycles that do not fall within the standard range, and that birth control, aging, and even stress can all affect cycle length.

I often smile when I remember an interaction two of my students had a couple of years ago. After teaching the female reproductive system, a male student turned to a female student, ashen-faced, and mumbled, "I didn't know you all had all that going on." She laughed and replied, "You have no idea." Until recently, my teaching did not create space to explore and admire the complexity of a healthy human body. I am grateful that today's students have pushed me to question my teaching and move beyond the myth that the average defines us.

About the Author

Mira Kolodkin is a professor in the Department of Biology at Wilbur Wright College where she has taught anatomy and physiology for over a decade. She has a PhD in neuroscience from the University of Wisconsin at Madison, and a MS in management from the University of Illinois at Urbana-Champaign.

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Back to TOC

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Anatomy-Based Outreach in Osteopathic Medical Education: Impact on High School Student Awareness and Career Interest

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Abstract

Limited awareness of both osteopathic medicine and anatomy as professional pathways contributes to workforce gaps in medical education and training. Career interests are malleable during high school, and educational experiences can influence future career goals. Previous studies suggest that early exposure to anatomy through outreach initiatives may increase students' interests in healthcare, creating an avenue to promote osteopathic and anatomy careers. This study examined the impact of an Anatomy Outreach for Research and Teaching Advancement (AORTA) event designed to introduce high school students to anatomy and osteopathic medicine. During the 2024–2025 academic year, a total of 463 students participated in an AORTA session and were invited to complete a post-event survey assessing awareness of and interest in anatomy and osteopathy both before and after the session, as well as perceptions of the program. The survey found that 43.3% of respondents had awareness of osteopathic medicine as a career option prior to participating in the AORTA event; after participating, 78.5% reported increased knowledge of osteopathy, and 50.7% expressed interest in pursuing osteopathic medicine. Many students also reported increased knowledge of and interest in anatomy as a career pathway. Although direct pre–post statistical comparisons were limited by survey design, these findings suggest that participation in an AORTA event is associated with increased awareness of both osteopathic medicine and anatomy-related careers among high school students. These results support the role of anatomy outreach programs as a strategy for providing early exposure to clinical and educational career pathways essential to medical training. https://doi.org/10.21692/haps.2026.011

Key words: anatomy education, anatomy outreach, osteopathic medical education, hands-on learning, high school students

Introduction

Over recent decades, the number of osteopathic physicians (DOs) in the United States has steadily increased; however, there is a substantial disparity in the number of osteopathic and allopathic physicians (MDs) in the medical field. While structural factors such as the lower number of osteopathic medical schools contribute to this gap, application data suggest that differences in awareness and perception may also play a significant role. This incongruity persists despite allopathic and osteopathic physicians receiving the same core medical education, clinical training, and patient outcomes with osteopathic medicine distinguished by a focus on holistic patient care and manual diagnostic and treatment techniques (Russell et al., 2025).

During the 2025 application cycle, 159 allopathic medical schools collectively received over one million applications (AAMC FACTS 2025), where 44 osteopathic medical schools received just over 200,000 (Guercio, 2025). On a per-school basis, this corresponded to an average of 6,668 applicants per allopathic program (2025 FACTS, n.d.) compared to 4,340 applicants per osteopathic program (Guercio, 2025). Thus, osteopathic programs received approximately one-fifth of the total number of applications submitted to allopathic programs and, on average, 34.9% fewer applicants per school.

This discrepancy persists despite comparable foundational medical training and clinical competencies across both pathways. However, it is important to recognize that these figures do not represent mutually exclusive applicant pools. Many candidates apply to both allopathic and osteopathic programs, and comprehensive national data quantifying this crossover remains limited. As such, differences in applicant volume should be interpreted cautiously.

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One potential contributor to this imbalance is limited exposure to osteopathic medicine during the formative stages of career decision-making. Career interests are known to be highly fluid during adolescence and early adulthood, particularly between the ages of 16 and 22, and are strongly influenced by targeted educational experiences (Quinlan & Corbin, 2023). Despite this, relatively little research has examined awareness of osteopathic medicine among younger student populations, including high school students. Early exposure to osteopathic principles and practice may therefore represent an important opportunity to broaden understanding of the profession and expand the pipeline of future osteopathic physicians.

Concurrently, medical education faces a growing shortage of trained anatomists. Over the past 50 years, the number of doctoral-level anatomy graduates in the United States has steadily declined, while the average age of anatomy educators continues to rise, signaling an impending wave of retirements (Edwards et al., 2023). Anatomists are essential to medical training, particularly for hands-on donor-based (cadaveric) instruction that underpins the development of surgical skills and three-dimensional anatomical understanding. Without adequate recruitment and retention of anatomy educators, medical curricula risk becoming increasingly reliant on digital modalities, potentially diminishing depth of learning and clinical preparedness (Ali Chatha et al., 2026).

Educational outreach programs implemented at allopathic institutions have demonstrated that early, hands-on exposure to donor anatomy can increase student interest in healthcare careers and improve understanding of the role of anatomists in medicine (Zhang et al., 2016). One program conducted by the West Virginia School of Osteopathic Medicine exposes high school students and health learners to the tenets of osteopathic medicine through anatomy laboratory sessions (Wines, 2019). Their survey found that the vast majority of respondents reported a greater understanding of a career in osteopathic medicine after participating in their program (Wines, 2019).

Building on this evidence, the present study evaluates the Anatomy Outreach for Research and Teaching Advancement (AORTA) program implemented at the University of New England College of Osteopathic Medicine (UNE COM). The AORTA program was designed to introduce high school students to human anatomy and osteopathic medical education in a memorable way. This initiative aims to assess potential changes in student awareness of osteopathic medicine and interest in anatomy-related careers post-session, addressing both the osteopathic application gap and the emerging shortage of anatomy educators.

Methods

Research Approval

Project #1024-04 was determined to be exempt under Category 2 by the Office of Research Integrity of the University of New England.

Program Description

Through the AORTA Program, local high school students participated in a two-hour, hands-on educational session conducted in the anatomy laboratory at UNE COM. Sessions were led by a faculty member with assistance from medical student facilitators. All educational activities occurred independently of the research components examined here.

Each session began with a classroom-based presentation that introduced participants to the University of New England and UNE COM, the osteopathic medical profession and its foundational tenets, and the role of body donation in medical education. Laboratory safety guidelines and behavioral expectations were reviewed, reinforcing information provided to participants prior to the visit. Time was allotted for participant questions and preparation before entering the anatomy laboratory.

Upon entering the lab space, participants were strongly encouraged to wear gloves and handle specimens. Students were divided into four hands-on instructional stations - cardiopulmonary, central nervous system, abdominopelvic, and applied musculoskeletal anatomy – where they would spend approximately 20 minutes each.

The cardiopulmonary, central nervous system, and abdominopelvic stations emphasized gross anatomy using donor material. Stations utilized isolated organs from body donors, rather than intact donors, allowing focus on specific regions and pathologies. At each of these stations, facilitators followed a standard instructional sequence: identification of normal anatomical structures and their location in the body, discussion of key structure–function relationships, and presentation of selected pathological examples as a comparison to healthy anatomy and to reinforce clinical relevance. The musculoskeletal station combined donor prosections with additional instructional modalities. Participants examined knee replacement and shoulder specimens, alongside anatomical models, PowerPoint-based instruction, clinical imaging (e.g., radiographs), and short case-based discussions to reinforce anatomy. Facilitators introduced common musculoskeletal injuries and guided participants through basic clinical reasoning, emphasizing how anatomical knowledge informs diagnosis and imaging interpretation in medical practice. Across all stations, facilitators encouraged hands-on participation and questions from the participants, adapting their teaching based on group interest as related to anatomy and medicine (Figure 1). Table 1 describes the materials used and instructional goals of each AORTA event station.

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Figure 1. *A medical student facilitator leads a group of high school students in hands-on learning about spinal cord anatomy during an AORTA session. Written consent was obtained from the students to publish this photo.*

Table 1 – AORTA Station Descriptions

Volunteer Facilitators

AORTA sessions were facilitated by volunteer first and second year medical students from UNE COM. Each anatomical station was staffed by at least one facilitator, with most supported by two to promote small group engagement. Approximately 85 facilitators participated across all sessions. Facilitators guided hands-on donor-based learning, explained clinical relevance, and provided insight into medical education pathways.

Student Participants

Study participants were recruited from the pool of high school students who attended an AORTA session in the 2024-25 academic year. A total of 17 schools participated in the survey evaluating student perspectives and career goals before and after attending an AORTA session. Sixteen schools traveled from southern and central Maine, and one from New Hampshire. The average distance traveled from participating schools to the University of New England (UNE) Biddeford campus was 51.1 miles. Across these schools, 463 students attended AORTA sessions, averaging 27.2 students per session.

Post-Event Survey

One week following participation in the educational session, students were invited to complete an anonymous, investigator-developed online survey. The survey used a retrospective pre-then-post design, in which participants completed a single post-session survey and were asked to reflect on and estimate their knowledge and interest both before and after participating in the AORTA session. Unlike a traditional pre–post design that administers separate surveys at multiple time points, this approach captured participants' self-perceived change retrospectively within one survey administration. This design allowed the investigators to decrease the total number of surveys administered, simplify the consent process, and mitigate participant attrition. The post-session survey consisted of 23 questions divided into three sections: 10 questions collected demographic information and student academic goals; 8 assessed participants' retrospective self-reported understanding of anatomy, awareness of healthcare career options, and interest before and after participation in AORTA; and 5 evaluated student perspectives on the session, including satisfaction and opportunities for future program improvement (see Appendix 1).

continued on next page

Stations	Anatomic Specimen and Supplemental Material Used	Instructional Emphasis
Cardiopulmonary	Combined Heart and Lung Prosection	To demonstrate the spatial relationships between the heart, lungs, and mediastinal structures within the thoracic cavity and reinforce cardiopulmonary structure–function relationships.
	2 Healthy Lungs	To identify lung lobes, fissures, and bronchial anatomy while discussing ventilation and gas exchange.
	3 Healthy Hearts	To examine normal external and internal cardiac anatomy, including chambers, valves, coronary vessels, and inflow/outflow tracts.
	Heart with Cardiomegaly & Radiographic Images	To compare pathological cardiac enlargement with normal anatomy and discuss potential etiologies and functional consequences.
	Heart with Pacemaker & Lead Diagrams	To illustrate pacemaker lead placement and relate it to cardiac conduction.
	Heart with Double Bypass (CABG) & Procedural Diagrams	To demonstrate coronary artery anatomy, graft placement, and clinical indications for coronary artery bypass surgery.
Central Nervous System	Brain with Meninges Intact	To identify the dura, arachnoid, and pia mater and discuss their protective roles and clinical relevance.
	Brain with Cranial Nerves and Circle of Willis	1. To identify lobes, fissures, and key gyri and sulci and relate them to their function. 2. To examine cranial nerve origins and cerebral arterial circulation, emphasizing neurovascular anatomy.
	Midsagittal Brain & Ventricular Diagram and Radiographic Imaging of Hydrocephalus	To demonstrate ventricular anatomy, cerebrospinal fluid flow, and pathological ventricular enlargement.
	Brain with Spinal Cord Attached	To illustrate continuity between the brain and spinal cord and discuss central nervous system organization.
	Brain with Subdural Hematoma, Subdural/Epidural Hematoma Diagram, and Radiographic Imaging	To compare subdural and epidural hematomas and relate their clinical presentation to imaging findings.
Abdominopelvic	Healthy Liver	To identify lobes and surface anatomy while discussing liver function.
	Cancerous Liver	To compare normal and pathological hepatic anatomy and introduce concepts of disease-related structural change.
	2 Healthy Kidneys	To identify renal anatomy and discuss filtration and urine production.
	Kidney Model	To supplement donor specimens by highlighting internal renal structures and nephron organization.
	Healthy Postmenopausal Uterus	To identify uterine anatomy and discuss reproductive structure and function.
Musculoskeletal	Shoulder Prosection	To demonstrate musculoskeletal anatomy of the shoulder joint and discuss common injury mechanisms.
	Healthy Knee	To examine normal knee joint anatomy and relationships between bones, ligaments, and cartilage.
	Knee Replacement	To compare native with prosthetic anatomy and discuss indications for joint replacement surgery.
	Knee Model	To reinforce joint anatomy and aid visualization of structures not easily seen on prosection alone.

Table 1. *Materials used and instructional goals of each AORTA event station.*

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Surveys were distributed by classroom teachers, who were not members of the research team and did not provide clarification or guidance regarding survey content, one week after their participation in the event. This delay between the educational session and survey administration was implemented to minimize immediate post-session optimism bias. Surveys required approximately 15 minutes to complete.

Data Collection

The post-event survey closed in May 2025, and all data were exported from Qualtrics XM in June 2025. Survey responses were cleaned and organized using Microsoft Excel (version 16, Microsoft Corp., Redmond, WA) prior to analysis. Quantitative analyses were conducted using SPSS (version 29, IBM Corp., Armonk, NY).

Data Security

The survey was anonymous, and no personally identifiable information, including IP address, was collected. Participation was voluntary, and students could skip any questions they preferred not to answer. Data were collected using Qualtrics XM (Provo, UT) and stored in password-protected files accessible only to the study team. All results are reported in aggregate to protect participants' confidentiality.

Ethical Considerations

All student interactions occurred at the UNE Biddeford Campus, primarily within the Alfond Center for Health Sciences. Students received a participant information sheet and parental notification form following their educational session. Survey completion served as implied consent for research participation.

Results

A total of 17 schools received the post-participation survey. Of the 463 students who were given the opportunity to complete the survey, we received 349 valid responses, yielding a response rate of 75.4%. Participants ranged in age from 14 to 19 years, with a mean age of 16.8 years (SD of 0.90) and a mode of 17. Most respondents were in the 12th grade (56.8%), followed by 11th grade (37.2%), 10th grade (5.2%), and 9th grade (0.9%).

Of all respondents, 225 (64.5%) identified as female, 118 (33.8%) identified as male, 3 (0.9%) identified as nonbinary, and 3 (0.9%) preferred not to answer. The majority of students identified their ethnicity as white (85.1%). Other reported ethnic identities included African American (9.8%), Indigenous (6.3%), Asian (4.0%), Pacific Islander (0.3%), and other (1.1%). Over 99% of students selected two or fewer ethnicity categories.

Regarding academic coursework (Table 2), most respondents reported completing chemistry (68.7%), anatomy & physiology (66.7%), and biology (53.4%). Additional courses commonly reported include physics (34.8%), earth science (29.9%), and environmental science (12.6%).

The majority of students reported plans to pursue a bachelor's degree (84.0%). Smaller proportions indicated plans to complete an associate's degree (6.3%) or attend technical school (1.2%), while 4.8% reported no academic plans and 3.6% selected "other." Among students planning to pursue a bachelor's degree, 158 (47.3%) reported intent to attend a professional school; professional interests included osteopathic medical school (20.1%), allopathic medical school (15.4%), and physical therapy programs (11.8%).

Science Course	Number of Students Reported Taking Course (n)	Percent of Cases (%)
Anatomy and Physiology	232	66.7
(AP) Biology	186	53.4
Physics	121	34.8
Earth Science	104	29.9
Chemistry	239	68.7
Forensics	19	5.5
Astronomy	10	2.9
Environmental Science	44	12.6
Other	36	10.3

Table 2. *High school science coursework reported by participants, with respondents permitted to select all that apply. Common courses written in the "other" category included sports medicine and physical science.*

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Students were also asked binary (yes/no) questions assessing awareness of anatomy and osteopathic medicine as potential career pathways before and after the AORTA session (Table 3).

Participants rated their overall experience with AORTA and their likelihood of recommending the program to peers on a 5-point Likert scale (1 = poor/very unlikely; 5 = excellent/very likely). Most respondents rated their overall experience (95.7%) and likelihood of recommending the program (88.3%) as 4 or 5, with 5 representing the modal response for both measures.

Open-ended survey responses were analyzed to identify common themes related to their favorite aspects and areas for improvement. Students most frequently cited viewing donor specimens (49%), hands-on interaction with specimens (42.4%), and direct engagement with medical student mentors (6%) as their favorite parts of the program (Table 4).

When asked about potential improvements, nearly half of the valid responses indicated that no changes were needed (47.5%). Among those suggesting changes, the most common theme related to program or station duration

Domain	Survey Question	Number of Respondents Selecting "Yes" (n)	Percent of Respondents Selecting "Yes" (%)
Anatomy	Prior to the AORTA session, I was aware of anatomy as a career option.	262	81.1
	I have increased my knowledge about a career in anatomy.	301	92.2
	I have increased my knowledge in anatomy.	319	99.1
	As a result of the AORTA session, I am more interested in anatomy.	267	82.9
Osteopathic Medicine	Prior to the AORTA session, I was aware of osteopathic medicine as a career option.	151	46.9
	I have increased my knowledge about a career in osteopathic medicine.	274	84.8
	As a result of the AORTA session, I am more interested in osteopathic medicine.	177	55
Healthcare	As a result of the AORTA session, I am more interested in healthcare.	248	76.8

Table 3. *Proportion of respondents answering "Yes" to survey items assessing awareness and interest in anatomy, osteopathic medicine, and healthcare careers before and after participation in AORTA. Response totals vary by item due to optional survey completion.*

Response Theme	Number of Responses (n = 302)	Selected Open-Ended Response
Seeing/Looking at Specimens or Specific Organs	148	"I enjoyed getting to see all the organs and structures I have already learned in Anatomy so it helped increase my knowledge."
Hands-On with Specimens	128	"Touching and feeling actual human organs and body parts because that is likely something you will never experience in your life."
Medical Student Facilitators	18	"Being able to be taught by current medical students who enjoyed having an opportunity to be the ones teaching."
Other Educational Aspect	10	"I really liked the shoulder and knee part because it taught me more about the issues I have with joints that doctors haven't been able to explain, same with the heart section and issues with that"

Table 4. *What did AORTA participants say was their favorite part of the session? This table groups open-ended responses by theme; selected responses are related to associated theme.*

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(22.5%). Notably, only 7.8% of those responses suggested decreasing time, while the remainder recommended increasing time. Additional suggestions included adding more organ system stations (8.8%), modifying educational materials (12.7%), and changes related to the anatomy lab setting (10.2%). Please see Table 5.

Discussion

Previous anatomy outreach initiatives described in the literature have demonstrated benefits including increased student interest in healthcare careers, improved understanding of human anatomy, and enhanced engagement with science education (Zhang et al., 2016; Wines, 2019). Notably, many of these programs have been implemented within allopathic medical institutions. The relative absence of published outreach models originating from osteopathic schools uncovers the importance of examining similar initiatives within the osteopathic context.

Participation from 17 schools across two states suggests that demand for anatomy-based outreach extends across multiple educational settings. Although the program was implemented through a single institution and primarily served schools within the surrounding region, it has continued to generate interest from both rural and metropolitan communities throughout its first 2.5 years of operation, with demand occasionally exceeding available session capacity. While AORTA emphasizes osteopathic medicine and anatomy education, anatomy also serves as a gateway to discussions surrounding numerous scientific, healthcare, and educational careers. Similar programs may be adapted to promote awareness of a variety of professional pathways without abandoning anatomy as the core educational focus. These findings support the feasibility of implementing similar initiatives at institutions with greater geographic access and more diverse student populations.

A notable strength of this study was the high survey response rate (75.4%). On survey distribution, teachers were instructed not to offer incentives or participation credit for survey completion. However, because surveys were distributed during scheduled class time, it is possible that dedicated in-class administration contributed to the elevated response rate. While we cannot definitively determine the extent to which classroom delivery influenced participation, it likely led to higher completion rates than surveys distributed for voluntary completion outside of school hours.

Our data suggest that programs such as AORTA may meaningfully influence high school students' awareness of anatomy and osteopathic medicine as viable career pathways. Over half of respondents expressed interest in osteopathy as a professional pathway after the session. By introducing students to donor-based anatomy alongside core principles of osteopathic education, the program offers exposure to both biomedical science and the philosophy behind osteopathic training.

Response Theme	Number of Responses (n = 284)	Selected Open-Ended Response
Nothing/No Change	135	"I wouldn't change anything!"
Time Changes (more or less time)	64	"Maybe just making it longer so we can learn more and go more in depth about each organ."
Adding Another Station or More Specimens	25	"I'd add more organs/stations. This is probably not realistic, but I just thought it was so interesting and the more stuff to learn there had been, the better."
Other - Educational Item (e.g., changes to station design, introduction lecture, etc.)	36	"Parts seemed disjointed-- i.e, the shoulder and knee station had sort of a quiz baked in, while others didn't. I liked the student participation aspect."
Other – Lab Setting (e.g., smells/masks, seating during session)	29	"I would see if masks could be provided to help with the heavy scent."

Table 5. *What changes do AORTA participants suggest being implemented in future sessions? This table groups open-ended responses by theme; selected responses are related to associated theme.*

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An interesting finding was that a greater proportion of participants initially selected their career interest in osteopathic medical school rather than allopathic medical school. Given that there are more allopathic programs nationally, and data suggest there are consistently more allopathic applications than osteopathic applications, we hypothesize that this may reflect the regional context in which this program was delivered. UNE COM is the only medical school in Maine and serves as a visible local pathway into medicine. Increased institutional familiarity and exposure to osteopathic medical students may have influenced reported interest. However, because baseline pre-session interest in osteopathic versus allopathic pathways was not assessed using matched pre–post measures, it is unclear whether this distribution reflects pre-existing preferences or post-session influence. Future studies incorporating paired baseline measures of professional interest would help clarify whether osteopathic interest exceeds allopathic interest prior to structured exposure.

Demographic and coursework data provide important insights for future refinement of the AORTA program. Because many participants reported prior coursework in biology and anatomy and physiology, future sessions may build more deliberately on foundational anatomical knowledge rather than introductory concepts alone. This approach could allow for deeper discussion of structure–function relationships, clinical correlations, and pathological examples. However, it is important to recognize that a subset of students reported limited or no prior exposure to anatomy and physiology coursework. This highlights the need for program content that remains accessible and adaptable across varying levels of academic preparation. While demographic variables in the present study were collected primarily to characterize the participant population rather than evaluate subgroup differences, future studies should explore whether responses to anatomy outreach and interest in osteopathic medicine differ across demographic groups and more diverse educational settings.

Additionally, most participants were in the 11th and 12th grades, with a mean age of 16.8 years, suggesting a level of academic and cognitive maturity that supports more advanced anatomical and career-focused discussions. Program content may therefore be tailored to incorporate greater emphasis on applied anatomy, clinical reasoning, and professional pathways, while maintaining flexibility to engage younger students or those with less formal science training.

The central focus of this survey was to evaluate whether participation in AORTA influenced students' awareness of anatomy and osteopathic medicine as potential career pathways. However, direct pre–post statistical comparison was limited by variation in question phrasing across survey items. Specifically, the items assessing baseline awareness *("Prior to the AORTA session, I was aware of anatomy/osteopathic medicine as a career option")*, perceived knowledge gain *("I have increased my knowledge about a career in anatomy/osteopathic medicine")*, and post-session interest *("As a result of the AORTA session, I am more interested in anatomy/osteopathic medicine")* were not identically structured. Because these questions assess connected but separate constructs, they cannot be directly paired for statistical comparison. Consistency in item construction will be addressed prior to future use of this survey. Nevertheless, the post-session interest item serves as a meaningful indicator of perceived program impact. While causation cannot be definitively established, students' self-reported increased interest suggests that AORTA may positively influence early perceptions of anatomy-related careers.

Another limitation involved the phrasing of coursework response options. Biology was listed as "(AP) Biology" to capture both Advanced Placement (AP) and traditional biology courses under a single category. However, this wording appeared to create ambiguity, as several respondents listed "Biology" and "Honors Biology" under the "Other" category. A similar pattern was observed with physics, where "AP Physics" was entered separately despite "Physics" being provided as a response option. This suggests that the inclusion of "AP" in select course titles may have unintentionally implied exclusivity rather than inclusivity. Future iterations of the survey would benefit from listing courses without AP designation and including a clarifying statement indicating that all levels (e.g., standard, honors, AP) should be categorized under the primary course title.

Participant feedback suggests that the AORTA program provided a positive experience. Nearly all participants reported their experience as high, with 95.7% selecting a score of 4 or 5 on a 5-point Likert scale. Open-ended questions further supported these findings. As explored in tables 4 and 5, most described having meaningful experiences with the content taught and often desired a longer event duration. One idea, as represented by the comment *"I would make the session longer because it felt a bit rushed at some points,"* stands out here. Requests for additional time may reflect variability in participants' prior coursework and educational backgrounds. Students with less foundational exposure may have required more time to process new concepts, whereas others may have sought greater depth. Future studies could assess this relationship. These findings highlight the importance of designing anatomy outreach programs that balance content depth with flexibility, allowing instruction to be adapted to a range of learning levels. Incorporating optional supplemental explanations or adjustable station pacing may improve inclusivity and enhance the learning experience for future participants.

Participants most frequently identified interaction with donors as their favorite aspect of the AORTA program. Qualitative data suggest that these sessions may help put what students are learning in their classrooms into perspective with anatomy and pathology. One participant

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stated *"My favorite part of the AORTA session was examining the brains of a stroke patient at the brain station. I was able to use my AP Psychology knowledge to recognize the major lobes, corpus callosum, cerebellum, etc. Further, it was simply transformative to see the [damage] the stroke had left in the patient's brain."* This response highlights how anatomy-based outreach may encourage students to integrate knowledge across disciplines and connect foundational concepts from classroom learning to real-world clinical and anatomical applications.

A limitation related to this survey item was the categorization of open-ended responses. Variability in phrasing and details made thematic grouping problematic. To address this, future survey iterations should include predefined options based on frequent themes from this study, while still retaining an open-ended comment section to capture unanticipated perspectives.

Beyond increasing awareness, AORTA provides a replicable outreach framework that other osteopathic institutions may adapt to strengthen early engagement within their own communities. Future longitudinal research will be necessary to determine whether participation in such programs correlates with greater application rates to pre-health tracks or graduate medical education programs. Potential approaches include incorporating a voluntary indicator within the UNE COM application to identify applicants who participated in AORTA during high school. Additionally, longitudinal follow-up surveys could be administered to former participants to assess subsequent educational trajectories, including application to or enrollment in anatomy-related or osteopathic training programs.

Conclusion

This study highlights the value of anatomy-based outreach conducted within an osteopathic medical school setting. By providing high school students with direct exposure to donor anatomy and near-peer mentorship, AORTA addresses gaps in awareness surrounding both anatomy and osteopathic medicine as viable career pathways. The program's structure offers a practical framework that may be adopted by other institutions seeking to strengthen early exposure to careers essential to medical education and clinical practice.

Although the event design and survey methodology were not without limitations, participant feedback indicated a consistently positive learning experience. Students frequently described the sessions as fun and informative, reinforcing the potential benefit of early exposure to anatomy in shaping student perceptions of anatomy-related and healthcare careers. Further longitudinal evaluation will be important to determine how early anatomy outreach influences long-term educational and career trajectories.

Acknowledgments

The authors gratefully acknowledge the volunteer AORTA facilitators for dedicating their time to teaching and supporting program sessions, as well as the anatomy faculty at UNE COM for their guidance and support. We extend our deepest appreciation to the anatomic donors, whose generous contributions make anatomy education possible. Their commitment to advancing medical education supports the development of future healthcare professionals, anatomists, and osteopathic physicians. We also thank the participating schools and teachers for their collaboration, and the students for their curiosity, professionalism, and respectful engagement throughout the program. Insights gained from these sessions will serve as a foundation for continued program development and future scholarly work.

About the Authors

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Appendix 1. Student Post-Event Survey

Item	Response Format
Student Information	
1. What was your age on your last birthday?	[Drop Down]
2. Please select the gender with which you most identify:	Select all that apply: ☐ Male ☐ Female ☐ Other (please explain) [Text box] ☐ I would prefer not to answer
3. Please select your grade level:	[Drop Down]
4. Please select the ethnicity(ies) with which you most identify:	Select all that apply: ☐ Black or African American ☐ American Indian or Alaskan Native ☐ Asian ☐ Hispanic ☐ Native Hawaiian or another Pacific ☐ Islander ☐ White ☐ Other (please explain) [Text box]
5. What courses have you taken or are taking currently (in high school) that are related to science?	Select all that apply: ☐ Anatomy (and Physiology) ☐ (AP) Biology ☐ Physics ☐ Earth Science ☐ Chemistry ☐ Forensics ☐ Astronomy ☐ Environmental Science ☐ Other (please list any other science course you have taken in high school) [Text box]
Academic/Career Goals	
6. What are your academic plans following high school?	Multiple choice: • Associate's degree (2 year) • Bachelor's degree (4 year) • Technical school • No academic plans • Other (please explain) [Text box]
7. If you plan to enroll in a degree-seeking program of any kind, what is your intended major/topic of study? (if not applicable, please respond "N/A")	[Text box]
8. Do you plan to attend a professional school/program following a traditional four-year degree? (eg. Medical or Dental school, Physical Therapy, Occupational Therapy, Physician's Assistant, etc.)	Multiple choice: • Yes • No
9. If you answered "Yes," to above question which type of program/school do you intend to attend?	Multiple choice: • Medical school • Dental school • Physical therapy • Occupational therapy • Physician's Assistant (PA) • Other (please explain) [Text box]
10. In a few sentences or less, what do you see yourself doing for a career?	[Text box]

Item	Response Format
Post-session Questions	
11. Prior to the AORTA session, I was aware of anatomy as a career option.	Multiple choice: • Yes • No
12. I have increased my knowledge about a career in anatomy.	Multiple choice: • Yes • No
13. I have increased my knowledge of anatomy.	Multiple choice: • Yes • No
14. As a result of the AORTA session, I am more interested in anatomy.	Multiple choice: • Yes • No
15. Prior to the AORTA session, I was aware of osteopathic medicine as a career option.	Multiple choice: • Yes • No
16. I have increased my knowledge about a career in osteopathic medicine.	Multiple choice: • Yes • No
17. As a result of the AORTA session, I am more interested in osteopathic medicine.	Multiple choice: • Yes • No
18. As a result of the AORTA session, I am more interested in healthcare.	Multiple choice: • Yes • No
19. On a scale of 1 – 5, with 1 being poor and 5 being excellent, how would you rate your experience with the AORTA program?	Multiple choice: • 1 • 2 • 3 • 4 • 5
20. On a scale of 1 – 5, with 1 being very unlikely and 5 being very likely, how likely would you be to recommend the AORTA program to a classmate or friend that has not participated?	Multiple choice: • 1 • 2 • 3 • 4 • 5
21. The part of the session I enjoyed the most was…	[Text box]
22. What would you change about the session?	[Text box]
23. Do you have any other comments about the session?	[Text box]

Back to TOC

EDUCATIONAL RESEARCH

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A Free, Web-Based 3D Model of the Brachial Plexus

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Abstract

The brachial plexus represents a fundamental component of medical school curricula; however, many students find difficulty in learning its complexity. Prior 3D models of the brachial plexus possess limitations, such as rigid levels of anatomical detail and/or financial barriers. To overcome these limitations, we sought to create a free, web-based model of the brachial plexus that offers a flexible level of detail for users. We sought to determine its effectiveness at increasing student knowledge, confidence, and reducing student stress. We created a web-based application with a 3D model of the brachial plexus via 3D modeling software. Through individual nerve selection and structural isolation, the model provides a gradient of detail that users can tailor to their own liking. The application was designed to be compatible with different devices that can run a web-browser. First-year medical students completed pre- and post-quizzes to assess the model's effectiveness, and survey questions were used to assess student confidence and stress levels. We were successful in creating a free, web-based application with a 3D model of the brachial plexus that can be accessed on any device that can run a web-browser. Use of the model increased student quiz performance, increased student confidence, and reduced student stress surrounding the brachial plexus. Given our model's accessibility combined with its effectiveness at increasing short-term memory, increasing student confidence, and reducing student stress, we believe that it has the potential to become a universal supplementary tool for students learning the brachial plexus. https://doi.org/10.21692/haps.2026.012

Key words: brachial plexus, medical education, 3D modeling

Introduction

The brachial plexus is a complex network of nerves that originates in the cervical and upper thoracic spinal cord and extends into the axillary region, providing sensory and motor innervation to the upper limb. Injuries to components of the brachial plexus often result in specific neurological deficiencies, and many common procedures, such as nerve blocks, require extensive knowledge of the brachial plexus to be performed safely (Brown, 1993; Feigl et al., 2020; Noland et al., 2019). Accordingly, learning and understanding the brachial plexus represents a fundamental component of medical school curricula, as proficiency of this plexus underpins effective understanding and informed clinical decisions regarding upper limb injuries. It is known that learning the brachial plexus is challenging for many medical students, with its anatomical complexity frequently cited as a primary source of difficulty (Brown, 1993; Feigl et al., 2020; Noland et al., 2019; Tianjun et al., 2025). In an effort to reduce cognitive overload and facilitate learning, prior studies have described alternative instructional strategies for teaching the brachial plexus, including the use of pipe cleaners (Lefroy et al., 2011; Yu et al., 2021) and pin boards (McMenamin, 2005). While these models demonstrated some educational benefit, their simplified nature may omit critical anatomical detail required for comprehensive understanding and future clinical practice (Feigl et al., 2020).

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Advances in digital technology have led to the creation of 3D anatomical models, offering promising supplemental tools and alternatives to traditional teaching methods (Erolin, 2019). This has led to more recent models of the brachial plexus (Stewart & Choudhury, 2015) that have maintained high-level detail and utilized technological platforms. Stewart & Choudhury used an iBook to teach students brachial plexus anatomy, which was successful in educating students; however, this model offered a more rigid, chapter-focused learning experience and required the acquisition of expensive technological platforms (Stewart & Choudhury, 2015). Other educational models that provide detailed brachial plexus anatomy, such as *Complete Anatomy* or *Visible Body*, offer comprehensive visualization but place limited instructional emphasis on the brachial plexus and may present financial barriers to student access (3D4Medical, 2024; Visible Body, 2025). Moreover, there have been few recent technological innovations in brachial plexus modeling for medical education, and to our knowledge, none that have explicitly incorporated medical students as co-creators in the design, development process, and application.

As a result, we created a web-based application with a 3D model of the brachial plexus that encompasses options for both simplicity and detail that is freely web-accessible through a link. The application allows for direct visualization of the brachial plexus in relation to bony structures. It allows for complete isolation of spinal nerves, trunks, cords, side branches, and terminal branches of the brachial plexus, offering simplicity of structures while still maintaining detailed visualizations. In addition, the model retains color-coding of spinal nerve contributions consistent with previous successful approaches (Lefroy et al., 2011; Yu et al., 2021) while also enabling isolation of these contributions through both 2D and 3D views. This flexibility allows learners to apply an individualized gradient of detail to the model tailored to their own learning. Furthermore, the application was designed to support unrestricted student exploration by intentionally omitting predefined learning checkpoints or chapters, thereby allowing students to freely navigate and engage with the model continuously without interruptions.

First year medical students were invited and provided access to the application during their musculoskeletal block immediately following their lecture on the brachial plexus. Participants completed pre- and post-assessments to evaluate knowledge acquisition. They also completed survey questions measuring stress and confidence levels related to the brachial plexus as well as their perceptions of the utility of 3D modeling in anatomy education.

The aim of this study was to develop a freely accessible, web-based application with a 3D model of the brachial plexus that allows users to select their preferred level of anatomical detail. We evaluated the effectiveness of the model in improving students' understanding of the brachial plexus, enhancing their confidence, and reducing their stress.

Methods

Model Creation

Modeling

Models of the skeleton and brachial plexus were created and refined using 3D modeling software Maxon ZBrush, Maxon Cinema4D, and Autodesk Maya. The nerves were modeled based on standard anatomical references (Drake et al., 2020; Gilroy et al., 2020; Netter, 2006). Models were retopologized to ensure efficiency in a web application.

Design

The application's user interface and functionality were meticulously designed to enhance learning about spinal root contributions to individual nerves and the pathways of the brachial plexus. The final layout of the application can be seen in Figure 1. To reinforce understanding, each spinal root contribution was visualized in a 3D model and simultaneously represented in a 2D diagram within the user interface (Figure 2). Additionally, consistent color coding was employed, linking the 3D visualizations to the 2D diagram in the user interface. Furthermore, selection of a nerve on the 2D diagram reveals that nerve's position on the 3D model as well as its sensory and muscle innervations (Figure 3). These correlations between the 2D interactive diagram and the 3D model were designed for students to relate the 3D model to their traditional way of learning (2D diagram). Finally, the nerves and bones can be isolated completely, as seen in Figure 4. All illustrations and icons were created using vector graphics software Adobe Illustrator, while wireframes and prototypes were developed with Miro and Adobe XD.

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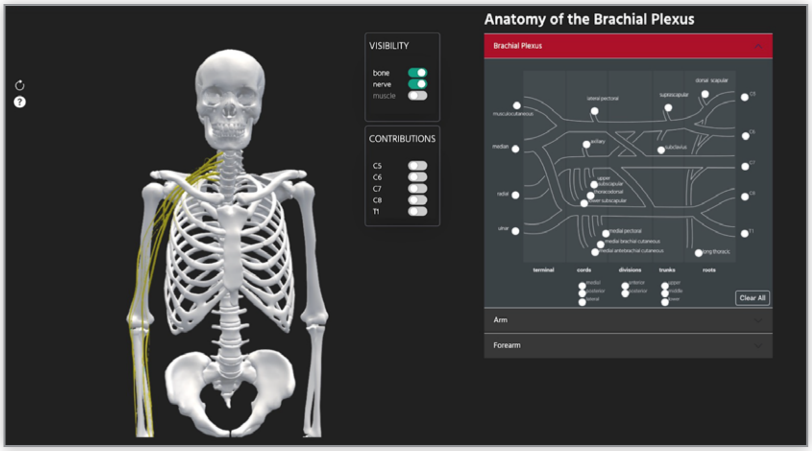

Figure 1. *Final Layout of the Model*

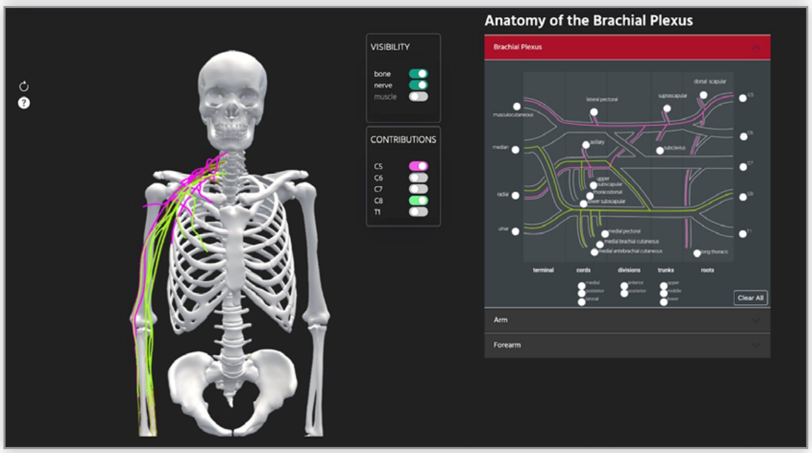

Figure 2. *Example of Spinal Contributions Shown on 3D Model and 2D Diagram*

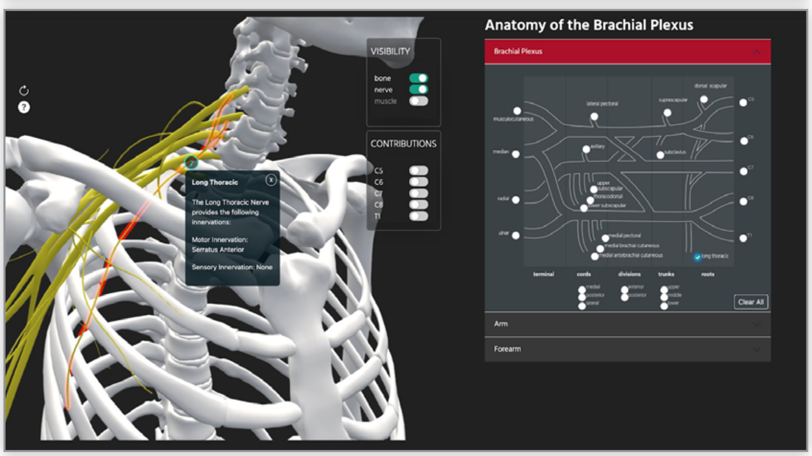

Figure 3. *Example of Nerve Selection*

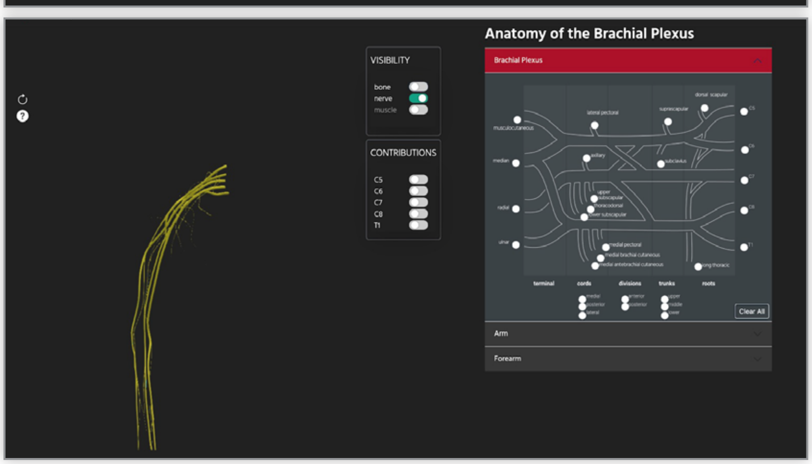

Figure 4. *Example of Nerve Isolation*

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Web Development

The interface of the web application was created using HTML, CSS and JavaScript languages, along with the Bootstrap framework. The interface is designed to be compatible with different devices that can run a web-browser, including desktop computers, laptops, tablets and phones. The rendering of the 3D model in a web environment, the functionality for toggling visibility of bones and nerves, and the annotations were implemented using ThreeJS library. To ensure smooth camera transitions, interpolations were created between key camera positions using the TweenJS library. For displaying the contributions in the 3D view, splines were created along the contribution paths using Maya. These splines were translated to 3D point-locations using Maya's Python API. These point locations were then used within ThreeJS to create splines for the web application. Once all the requirements were met and the application was tested for errors, it was hosted on a web server for the students to be able to access it. The model can also be interfaced to virtual reality (VR) and augmented reality (AR) headsets.

Student Assessment

A REDCap survey was created to assess student knowledge, confidence, and stress levels surrounding the brachial plexus. The survey housed a pre-quiz, the created web-application with the model, and a post-quiz all as separate instruments of the survey in the order as listed (Harris et al., 2009; Harris et al., 2019). Students were prevented from accessing the instruments out of order and were required to supply their institutional email to complete the survey. Upon completion of the pre-quiz, students were given access to the survey instrument housing the model. They were asked to spend at least 10 minutes studying the brachial plexus model, after which they could select an attestation statement acknowledging completion of this section. Selection and submission of the attestation statement allowed them to access the survey instrument housing the post-quiz. Upon completion of the post-quiz, students were emailed the link to the web-application, allowing them unlimited access. Model access was only granted if all components of the study were completed.

The pre- and post-quiz questions consisted of 5 multiple choice questions and were designed to test students' basic knowledge and spatial awareness of structures of the brachial plexus. Basic knowledge questions concerned spinal level contributions and muscle innervations of nerves of the brachial plexus. Spatial awareness questions were paired with an adapted diagram of the brachial plexus, of which an example can be seen in Figure 5 (Mattopaedea, 2009). To maximize internal validity, we purposefully used different pre- and post-quiz questions while matching the level of difficulty between the quizzes (Stratton, 2019). Example pre- and post-quiz questions can be seen in Table 1.

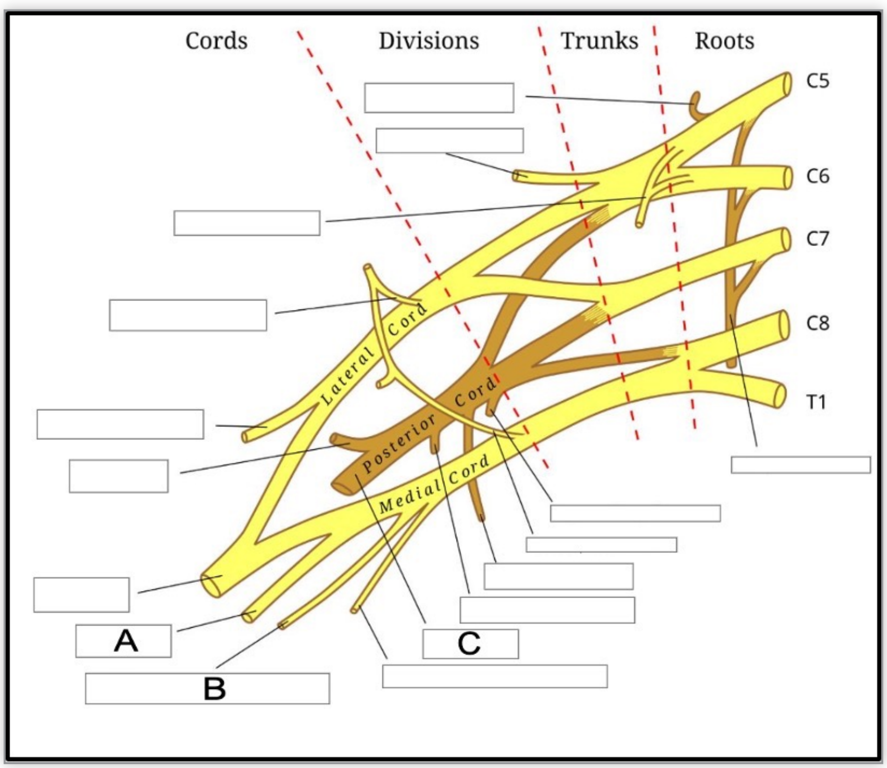

Figure 5. *Pre-Quiz Image for Spatial Awareness Questions*

Pre-quiz	**Post-quiz**
Example Basic Knowledge Questions	
The median nerve arises from the ventral rami of which spinal levels?	The radial nerve arises from the ventral rami of which spinal levels?
A. C6, C7, C8	A. C7, C8, T1
B. C6, C7, C8, T1	B. C6, C7, C8
C. C5, C6, C7, C8	C. C5, C6, C7, C8
D. C7, C8, T1	D. C5, C6, C7, C8, T1
Example Spatial Knowledge Questions	
What nerve is labeled by the letter B in the above image?	What nerve is labeled by the letter B in the above image?
A. Ulnar Nerve	A. Lateral Pectoral Nerve
B. Axillary Nerve	B. Medial Antebrachial Cutaneous Nerve
C. Lateral Pectoral Nerve	C. Axillary Nerve
D. Medial Antebrachial Cutaneous Nerve	D. Medial Brachial Cutaneous Nerve

Table 1. *Example Knowledge Questions of Pre- and Post-quiz*

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In addition, survey questions regarding confidence and stress levels surrounding the brachial plexus were embedded into the pre- and post-quizzes. In both quizzes, students were asked about their confidence in their ability to identify the branches and terminations of the brachial plexus. They were asked to rate their confidence as "Highly Confident," "Very Confident," "Mildly Confident," "Somewhat confident," or "Not Confident." Students were also asked about their stress levels around learning the brachial plexus. They were asked to rate their stress as "Highly Stressed," "Very Stressed," "Mildly Stressed," "Somewhat Stressed," or "Not Stressed." Furthermore, in the post-quiz, students were asked to what degree they agreed with the following statement: "Anatomical education would be improved by using 3D representations of the structures." Answer choices were "Strongly Agree," "Somewhat Agree," "Neutral," "Somewhat Disagree," and "Strongly Disagree." For survey questions, answer choices were represented via a Likert scale and mapped to integer values for comparison.

All first-year medical students at our institution were emailed a link to the REDCap survey immediately following their lecture on the brachial plexus. The survey was voluntary. This project was approved by the Institutional Review Board of the University of Nebraska Medical Center (IRB #[redacted]), and informed consent was obtained from all participants by implied consent. Participants were informed that this survey was conducted for research purposes and that completion of the survey represented consent to participate.

Analysis

Student emails were converted into unique IDs for deidentification. Student responses were excluded if they did not complete all components of the survey, had attempted the survey more than once, or spent less than 10 minutes studying the model. After data collection, students who spent an implausible amount of time (> 23 hours on the model or > 1 hour on the pre- or post-quizzes) on any section were removed. The overall pre- and post-quiz scores were compared using a paired, two-sided Wilcox-signed rank test. Pre- and post-quiz scores for students who scored less than 5/5 on the pre-quiz were also compared using a paired, two-sided Wilcox-signed rank test. Box plots were used to visualize the distribution of pre- and post-quiz scores. Student responses regarding confidence and stress levels before and after studying the model were compared via paired two-sided Wilcox-signed rank tests. Numerical values of 1-5 were assigned to each confidence rating as listed previously, with 1 representing "Highly Confident" and so forth. Numerical values of 1-5 were also assigned to each stress rating as listed previously, with 1 representing "Highly Stressed" and so forth.

Survey data was collected via a Likert scale and treated as ordinal. Side-by-side bar charts were used to show the number of students in each category before and after studying the model, and box plots were used to compare the distribution of scores before and after studying the model. Student responses to the statement "Anatomical education would be improved by using 3D representations of the structures" were split into percentages for each answer choice. Statistical analysis was performed using R (version 4.3.2). The R package dplyr was used for data transformation, and the packages ggplot2, ggpubr, ggrepel, and RColorBrewer were used for graphics creation (Kassambara, 2025; Neuwirth, 2022; Slowikowski, 2024; Wickham et al., 2025; Wickham, 2016).

Results

Responses

A total of 67 responses were received representing 60 students and one respondent who failed to answer any questions. Of the 60 students who began the survey, a total of 40 students completed all components of the survey (pre-quiz, model study, and post-quiz). Each duplicated student was removed via ID matching. Of the remaining students, 26 spent ten or more minutes studying the brachial plexus model. Of this group, an additional 4 students were removed: 2 students spent 1+ days with the model open (1,327 minutes and 8,255 minutes), 1 student spent greater than 1 hour on the pre- and post-quizzes, and 1 student had previously opened the survey. After filtering, the study population consisted of 22 students. The average time spent on the pre- and post-quizzes among participants was 2.24 minutes (+/- 0.84) and 2.14 minutes (+/- 1.29), respectively. The time spent studying the model was right-skewed with an average study time of 27.51 minutes (+/- 26.66) and a median of 15.32 minutes (IQR = 11.52-31.40).

Pre- and Post-Quizzes

Among the entire study population, the median pre-quiz score was 3 (IQR = 2-5), and the median post-quiz score was 5 (IQR = 4-5), which was found to be a statistically significant increase (P = 0.0305; Figure 6A). Among students who earned less than 5 on the pre-quiz (14/22 students), the median pre-quiz score was 2.5 (IQR = 2-3), and the median post-quiz score was 4.5 (IQR = 3-5), which was also found to be a statistically significant increase (P = 0.0219; Figure 6B).

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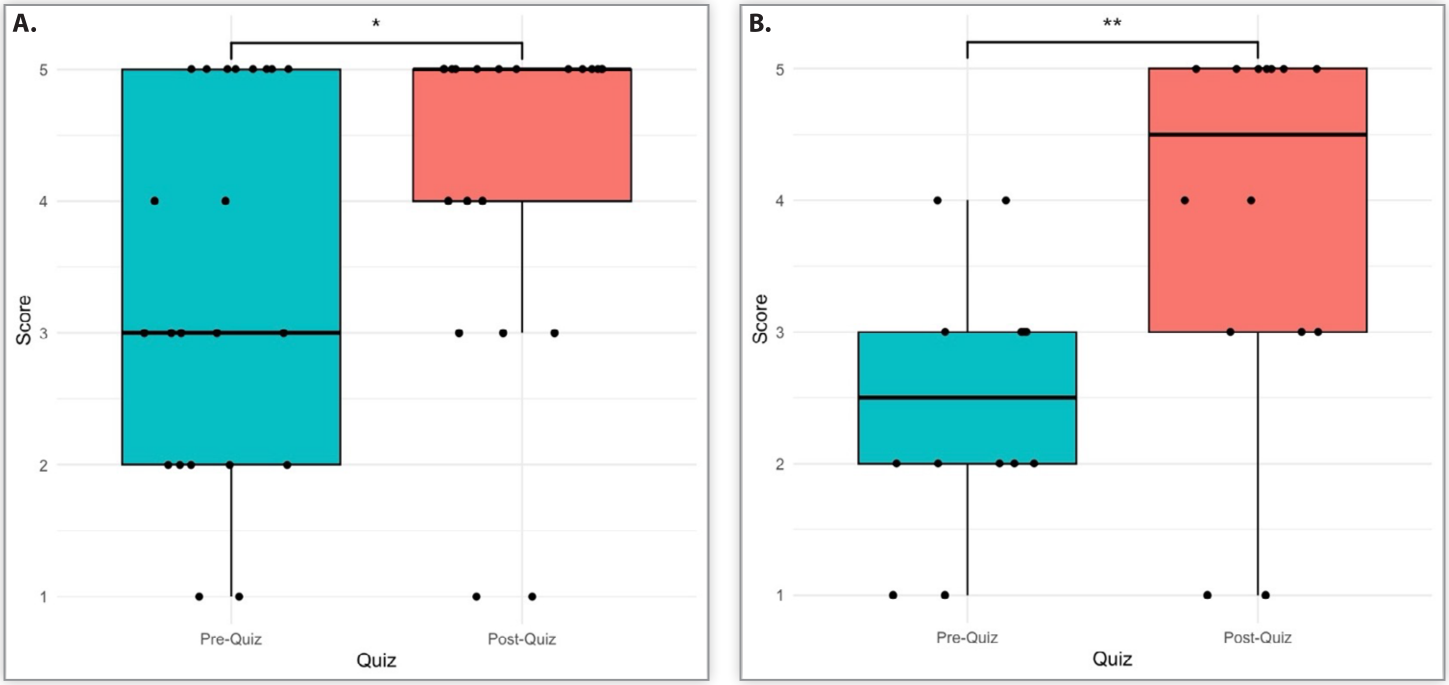
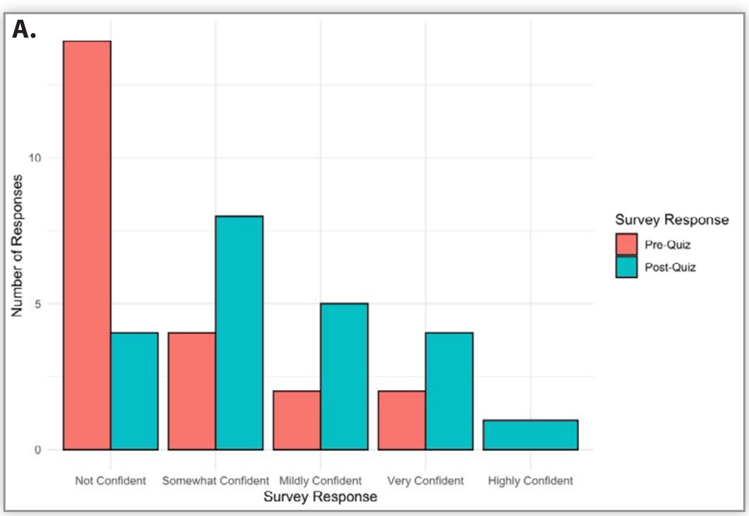


Figure 6.
A. *Box plot depicting the distribution of pre- and post-quiz scores for all students in the study (n=22).*
B. *Box plot depicting the distribution of pre- and post-quiz score for all students that earned less than 5/5 on the pre-quiz (n=14). * p-value 0.0305, ** p-value 0.0219*

Confidence and Stress Levels

The median confidence level prior to studying the model was 5 ("Not Confident"; IQR = 4-5), and the median confidence after studying the model was 4 ("Somewhat Confident"; IQR = 3-4), representing a significant increase in confidence level (P = 0.00056; Figure 7). The median stress level prior to studying the model was 2 ("Very Stressed"; IQR = 1-2.75), and the median stress level after studying the model was 3 ("Mildly Stressed"; IQR = 2-4), representing a significant decrease in stress level (P = 0.0012; Figure 8).



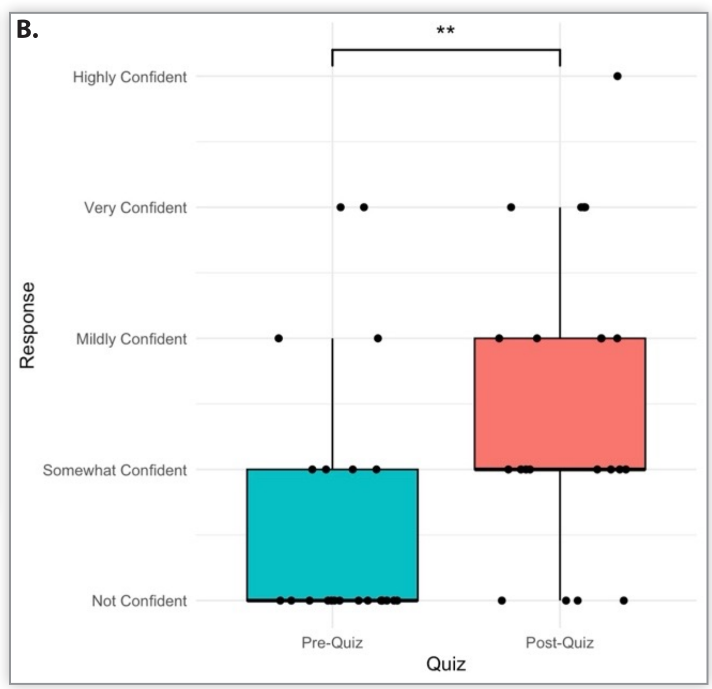


Figure 7.
A. *Bar Chart depicting the number of students at each reported confidence level before and after studying the model (n=22).*
B. *Box plot depicting the distribution of reported confidence before and after studying the model (n=22). ** p-value 0.00056*

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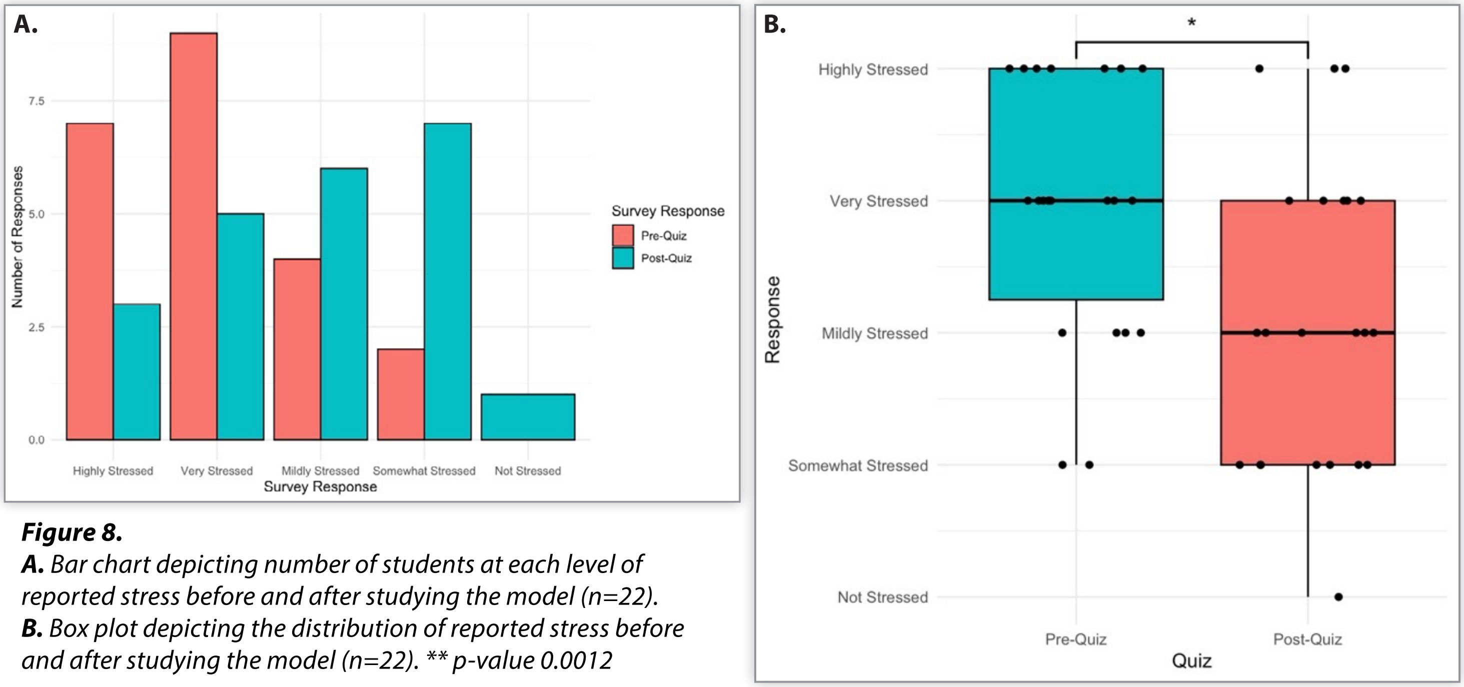

Figure 8.
A. *Bar chart depicting number of students at each level of reported stress before and after studying the model (n=22).*
B. *Box plot depicting the distribution of reported stress before and after studying the model (n=22). ** p-value 0.0012*

Opinions on 3D Models

Regarding the question "Anatomical education would be improved by using 3D representations of the structures," most students (15/22 students, 68.18%) strongly agreed with the statement, and another 4 students (18.18%) somewhat agreed. Only 3 students were neutral or disagreed with the statement: 1 student (4.55%) stated they were neutral, 2 students (9.09%) stated they somewhat disagreed, and 0 students strongly disagreed.

Discussion

In this study, we successfully developed a free, web-accessible application with a 3D model of the brachial plexus that allows learners to freely explore this structure while adjusting the level of detail to their individual needs. Using a REDCap survey, we evaluated the model's impact on student learning, confidence, and stress. Following interaction with the model, students demonstrated improved quiz scores, increased confidence, and reduced stress levels. These findings suggest that the model may serve as an effective supplemental educational tool for enhancing understanding of this complex anatomical structure. Given its accessibility and adaptability, the model has potential for broader application in anatomy education and may help address common challenges associated with learning complex anatomical relationships.

Model

Prior brachial plexus models are often simplified, have predefined learning checkpoints or chapters, place limited instructional emphasis on the brachial plexus, and/or present financial barriers to student access (3D4Medical, 2024; Lefroy et al., 2011; McMenamin, 2005; Visible Body, 2025; Yu et al., 2021). We sought to improve upon these limitations. The model we created consists of a skeletal body from the pelvis upward with the brachial plexus overlaid on top to represent accurate anatomical landmarks. In addition, a 2D diagram of the brachial plexus was included alongside the 3D model, allowing students to correlate 2D and 3D views while selecting a particular nerve and reviewing its course, spinal level contributions, and sensory and muscle innervations. This unique combination was sought to increase deeper understanding of the brachial plexus and offer increased flexibility and adaptability to students using the application (Anderson et al., 2019).

Additionally, increased detail and extraneous information can hinder learning (Rey, 2012). To address this, we designed our application to allow isolation of structures and individual spinal level contributions, providing a level of simplification beyond that of previous models while preserving anatomical relationships (Lefroy et al., 2011; McMenamin, 2005; Yu et al., 2021). This feature aligns with cognitive load theory by reducing extraneous load from viewing the entire brachial plexus at once, while also helping learners manage its intrinsic complexity. By focusing on individual components before integrating them into the larger network, learners may progressively build understanding without becoming overwhelmed by visual complexity (Chen et al., 2023). Also,

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our application's uninterrupted user interface, without predefined checkpoints or chapters, enhances accessibility when compared to other models (Stewart & Choudhury, 2015). Furthermore, because it is freely available on any device via a web link, it provides a cost-effective alternative to other advanced resources, such as *Complete Anatomy* (3D4Medical, 2024), *Visible Body* (Visible Body, 2025), and the iBook (Stewart & Choudhury, 2015).

Pre- and Post-Quizzes Alongside Confidence and Stress Levels

In addition to the practical advantages of our model, this study demonstrates its effectiveness in enhancing students' short-term understanding of the brachial plexus. Overall post-quiz scores were significantly higher than pre-quiz scores, with students who seemingly had less knowledge of the brachial plexus showing significant increases in post-quiz scores. Previous research has shown that individuals with lower self-perceived knowledge often experience increased stress and anxiety related to academic subjects (Lu et al., 2024), which can be exacerbated when presented with large amounts of information (Ma, 2025), ultimately negatively affecting academic learning and performance (Chen & Maziha, 2025; Ma, 2025). Our model was therefore designed to minimize stress for students who may perceive themselves as having less knowledge while still maintaining a complete, fully detailed anatomical model. Quiz results suggest this goal was partially achieved, and this effect is further supported by survey data: student confidence increased, while stress levels decreased. This data suggests that our model does not overwhelm students; rather, it appears to enhance their confidence. Given that prior studies have linked increased confidence, academic achievement and learning outcomes (Hayat & Shateri, 2019; Luo et al., 2023; Meng & Zhang, 2023), the observed gains in confidence may further support students' mastery of the brachial plexus.

3D Modeling and Future Directions

Nearly 90% of survey respondents agreed, to some degree, that anatomy education would be improved by using 3D models. This finding aligns with previous studies (Sevindik et al., 2024; Tripodi et al., 2020) and reinforces the rationale for the present study. Students appear to recognize that 3D modelling can be very useful in anatomical education, particularly after utilizing our model, suggesting that further evaluation of this model via different modalities may be warranted. While this model is freely accessible via a web-link, this model can also be viewed through VR and AR headsets. Given evidence that VR and AR can effectively support anatomy education by providing better depth perception and spatial understanding (García-Robles et al., 2024), future studies should explore the efficacy of our model through VR and AR platforms.

Limitations

There are several limitations to this study. First, the sample size is limited. To ensure study validity, we applied selective inclusion criteria for student responses, as detailed in the results section, which resulted in the analysis of only 22 responses. Subsequent studies should aim to use larger student populations if possible. Second, we were unable to control if students used outside resources while taking quizzes or using the application. We attempted to mitigate this by excluding responses in which students spent prolonged periods of time on any given section of the survey (> 60 minutes on pre- or post-quizzes, and > 180 minutes on the model) and excluding a student who had previously attempted the pre-quiz, though it remains possible that additional resources were consulted. Additionally, participation in this exercise was voluntary and ungraded, so there was no direct incentive for performance, and student activity during quizzes was not monitored. Finally, to minimize participant burden and maximize response rates, the survey was kept brief and did not include questions regarding students' preferences or feedback on the application. Future research should aim to address these limitations by incorporating larger sample sizes, controlling assessment conditions, and providing detailed feedback mechanisms.

Conclusion

In conclusion, we successfully developed a free, web-based application with a 3D model of the brachial plexus that overcomes limitations of prior brachial plexus models while effectively supporting student learning. Use of the application increased student quiz performance, increased student confidence, and reduced student stress surrounding the brachial plexus. Given its accessibility and demonstrated educational benefits, this application has the potential to serve as a widely available supplemental teaching tool for students both nationally and internationally.

For those who would like to explore this further, this is the link to the Brachial Plexus Application: https://webmedia.unmc.edu/iexcel/apps/brachialPlexus/ . Of note this model contains additional anatomical modeling of the hand and forearm not discussed in the methods for this manuscript. These areas will be used for potential future development and potential muscle additions.

Disclosure

This research was conducted in accordance with the Institutional Review Board at our institution, and APA ethical standards were followed. We have no known conflicts of interest to disclose. Of note, the web-based application discussed in this manuscript was previously awarded the 2025 Image of Distinction Award from BioCommunications Association, and the model is currently being hosted on their website at https://bca.org/BioImages-Winners-2025-Multimedia/Multimedia.

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Back to TOC

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Exploring the Use of Cooperative Quizzes on Students' Sense of Belonging in Anatomy and Physiology

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Abstract

This study explored the influence of weekly cooperative quizzes on students' sense of belonging. Participants were community college anatomy and physiology (A&P) students from three course sections (in-person and online) with the same instructor. Students completed surveys with quantitative (Likert-scale) and qualitative (open-response) questions at the beginning and end of the course. Analysis of the open-response qualitative data revealed six themes related to a sense of belonging: (1) emotional safety, (2) positive group interactions, (3) negative group interactions, (4) perceived content understanding, (5) instructor approachability, and (6) noncontributing factors. The findings show that students reported a high level of agreement with survey statements measuring sense of belonging, and students' qualitative responses suggested that cooperative quizzes contributed to sense of belonging. The findings suggest that instructors can use cooperative quizzes to encourage students' sense of belonging, particularly when paired with instructor practices that foster positive group interactions during the quizzes. https://doi.org/10.21692/haps.2026.018

Key words: cooperative quizzes, sense of belonging, community college, active learning, collaborative learning

Introduction

Students' sense of belonging is defined as the feeling of being "accepted, respected, included, and supported by others", such as teachers and peers, in the academic classroom setting (Goodenow, 1993). This concept plays a crucial role in higher education (Strayhorn, 2019). For example, a literature review conducted by Gilani & Thomas (2025) across 118 studies on students' sense of belonging found that belonging was significantly associated with numerous positive academic outcomes, including improved academic performance (Cwik & Singh, 2022; Sotardi, 2022), intention to persist academically (Hausmann et al., 2007), academic engagement (Gillen-O'Neel, 2021), retention (Davis et al., 2019; Fink et al., 2020; Murphy et al., 2020; Russell et al., 2025), and positive mental health (Veldman et al., 2023).

Other research indicated that belonging was associated with academic motivation (Slaten et al., 2025). Goodenow (1993) suggested that students' sense of belonging may be an important contributor to school motivation, participation, and effort. Similarly, self-determination theory defines relatedness as the need to feel connected to others and suggests that when this need is unmet, motivation may be reduced (Deci & Ryan, 2000).

However, these findings, largely derived from four-year institutions, should not be assumed to generalize to other educational contexts such as community colleges. Research on students' sense of belonging cannot be broadly generalized across student populations, as belonging is inherently tied to students' social identities (Strayhorn, 2019).

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For example, at four-year institutions, first-generation and racial-ethnic minority students reported a lower sense of belonging than their peers, whereas the opposite pattern was observed at two-year colleges (Gopalan & Brady, 2020). Overall, current research provides limited insight into how a sense of belonging, and the positive academic outcomes associated with it, operate in community college settings. The present study seeks to help address this gap.

Additionally, little of the existing literature examined how specific pedagogical practices can foster students' sense of belonging (Harben & Bix, 2019). Because positive peer interactions and feeling valued within a group are central to belonging (Strayhorn, 2019), cooperative learning practices appear particularly promising. A small but growing body of research supports this claim. For example, one study compared two groups taking the same asynchronous online physiology lab, one with required group work and one without, and found that students required to engage in group work reported a significantly greater sense of belonging than those who worked individually (Carr et al., 2024).

Similar results have been observed in in-person contexts. In an introductory STEM course, researchers examined pre- and post-levels of sense of belonging across three assessment formats: individual iClicker questions, in-class group activities, and peer-discussion iClicker questions. The study found a significant effect of assessment type on a sense of belonging: students who participated in either in-class group activities or peer-discussion iClicker questions reported the highest post-intervention levels of belonging (Harben & Bix, 2019). Moreover, research shows that several active-learning strategies, such as in-class group exercises with discussion, boost student confidence and facilitate efforts by instructors to encourage student participation in the classroom (Freeman et al., 2011). These strategies might contribute to a greater sense of belonging for students.

Because classroom belonging is influenced by opportunities for interaction, evidence-based instructional practices (EBIPS) that promote peer engagement may help support students' sense of belonging. One type of EBIP is cooperative quizzes. Despite research on both students' sense of belonging and cooperative learning practices, little research has specifically examined whether cooperative quizzes influence students' sense of belonging in A&P courses. The present study aims to investigate a relationship that has not yet been empirically examined: whether cooperative quizzes contribute to students' sense of belonging.

Cooperative quizzes are an evidence-based instructional practice (EBIP) in which students first take a quiz individually and then have the opportunity to discuss their individual answers in groups with other students. During peer discussions, students are encouraged to help one another and are allowed to change their individual answers (Jensen et al., 2002). Some cooperative quizzes will ask students to reflect on the same questions they had to answer individually, while other cooperative quizzes will ask students to discuss similar questions. Like other forms of assessments used in A&P, cooperative quizzes utilize a variety of question types such as fill in the blank, multiple-choice questions, and short essay questions (Rao et al., 2002). This instructional practice requires students to work with one another, allowing them to learn from others who know more, or when they understand the material well, by helping those who still struggle with it. By working with their peers, this type of practice is meant to help students with test-taking and to gain a better knowledge of the subject while creating a better class environment (Jensen et al., 2002).

The literature currently indicates that cooperative quizzes support learning. For example, Cooke et al. (2019) found that students generally had a positive view of cooperative quizzes and that this type of assessment was especially beneficial to lower performing students. These last results are supported by Giuliodori et al. (2009), who found that in those groups in which students' individual answers differed, peer discussion significantly led students to change their answers to the correct option rather than the incorrect one. These results indicate that peer collaboration can help students perform better on assessments. It is also important to note that the gain in knowledge acquired during cooperative quizzes seemed to be enduring through time (Vazquez-Garcia, 2018), which indicates the effectiveness of cooperation for promoting long-term retention. Although these studies focus on measured learning performance, they provide important context for interpreting students' perceptions of cooperative quizzes as supporting their understanding and sense of belonging.

Since cooperative quizzes contribute to creating a positive class environment, the implications of this practice on a sense of belongingness should be investigated. Given the limited research directly examining cooperative quizzes and students' sense of belonging, this study takes an exploratory approach to investigate how cooperative quizzes may relate to students' perceptions of belonging.

Methods

This study sought to answer the following research question: How does the use of cooperative quizzes impact students' sense of belonging? It was conducted during the Fall 2022 semester at a community college in North Carolina. This project was approved by the IRB board of Forsyth Technical Community College, and informed consent was obtained from all participants. The students were enrolled in a 16-week A&P course with the same instructor. Three sections of A&P were invited to participate: two sections of A&P I (primarily serving nursing and physical therapy majors), and one section of a single-semester basic A&P course (intended for emergency medical services and allied health majors). Of the

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A&P I courses, one section was online and synchronous that met twice a week and the other was in-person lecture with flexible in-person labs. The basic A&P course was high-flex, meaning that each time the class met, students could choose to attend online or in-person.

Participants

Participants were students enrolled in A&P courses at a southeastern community college. Institutional data reports that the student population includes approximately 65% female students, with racial and ethnic representation of about 44% White, 25% Black, and 18% Hispanic students (Forsyth Technical Community College, n.d.). While demographic data were collected as part of the survey, the responses were incomplete. Therefore, institutional demographic data were used to describe the study participants. The courses primarily served students pursuing healthcare-related programs such as nursing and allied health. All students participated in the cooperative quiz intervention activities as an evidence-based instructional practice. Survey data were voluntarily collected from student participants from all three A&P sections. Participants received two bonus points for each completed survey, applied to the first and final exams respectively.

A principal investigator provided the instructor with a list of students who completed each survey at the end of the course. Students were not required to complete the first survey to be eligible for the bonus points associated with the final exam. A total of 71 students were enrolled across the three course sections based on census attendance. As a result, 16 students exclusively completed the beginning-of-course survey, 17 students exclusively completed the end-of-course survey, and 16 students completed both. A total of 49 students participated in at least one survey, with 32 responses collected from the beginning-of-course survey and 33 responses collected from the end-of-course survey.

Study Design

As an intervention, cooperative quizzes were implemented with all three sections eight times during the semester. Each of these quizzes consisted of no more than 5-10 questions based on class discussions, homework, and readings that would have been completed by the students before coming to class. The individual quizzes consisted of multiple-choice questions, while the cooperative quizzes were shorter and used a combination of multiple choice and short answer-based questions.

One person in each group was responsible for writing down the group answer on the answer sheet (in-person) or computer (on-line). For students attending in person, efforts were made to maintain consistent groups of 2–3 students for approximately 2–3 weeks, corresponding to the time between major assessments. Even when students were in the same group, different students were responsible for recording their group's answers each quiz each week. Group composition in the in-person classes occasionally changed due to attendance or enrollment shifts.

For students participating online, Zoom breakout rooms were randomly assigned during each session, resulting in group membership changing across quizzes. With the online students, the group quiz was set up as an individual submission since the learning management system did not allow for the creation of a group quiz. These group quizzes for the online students were discussed in Zoom rooms so that each person in the group agreed on the answers that would be submitted.

Across all formats, the cooperative quizzes served as the primary structured collaborative activity. In-person students also engaged in informal collaboration during laboratory activities and whole-class discussions. During cooperative quizzes, the instructor circulated among groups to clarify misconceptions, encourage participation, and support collaborative dialogue while allowing students to guide their own discussions. Cooperative quizzes were the primary active learning strategy in the classroom setting. Other instructional strategies included using gamified student response systems and traditional lab activities completed in groups. However, in both of these, the collaborative components were not essential to completing the activity and/or the formal assessment of their work. For example, students submitted lab reports and responded to a gamified response system as individuals.

To investigate sense of belonging, students were invited to answer a survey at the beginning and at the end of the course. In both surveys, quantitative data were collected using a Likert-scale instrument that measured feelings of belongingness adapted from Knekta et al. (2020) and Bollen & Hoyle (1990). These items capture key components of belonging relevant to the definition of this term such as feeling valued and included in a classroom. Qualitative data were gathered using open-ended questions eliciting responses about sense of belonging.

Survey Data Collection

The survey administered at the beginning of the course included two Likert-scale questions (below), which asked students to indicate their degree of agreement for a given statement. The statements were rated on a five-point scale: 1 = not at all, 2 = a little bit, 3 = somewhat, 4 = very much 5 = extremely.

- I feel that my opinions are valued in this class. (Knekta et al., 2020)
- I feel like I am a part of the community in this class. (Bollen & Hoyle, 1990)

This survey also included one open-response question:

- What does a sense of belonging mean to you in the context of this class?

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The survey administered at the end of the course included the questions listed above and two additional questions. The first was a Likert-scale statement that used the same five-point scale as the first survey:

- The group (cooperative) quizzes contributed to my sense of belonging to this class.

And the second was an open-ended question:

- How do you feel the group (cooperative) quizzes contributed to your sense of belonging in the class?

Data were collected using a Qualtrics survey, administered by principal investigators of the umbrella study (RECAPER). The principal investigators anonymized the results before sharing the data with the instructor (A.B.).

Data Analysis

Quantitative Likert-scale data were analyzed using descriptive statistics including medians and response distributions, rather than means and standard deviations. This approach avoids assuming equal intervals between response categories and aligns with recommendations for analyzing ordinal data (Liddell & Kruschke, 2018). Response distributions were examined by identifying the number of students selecting each response option for each Likert-scale item. In addition, non-parametric tests (Kruskal-Wallis and Wilcoxon signed-rank tests) were used to compare Likert-scale data belonging scores between sections and between the beginning and end of the course.

Qualitative data were analyzed inductively using thematic coding (Saldaña, 2021). First-round coding analyzed the three open-response questions separately by summarizing each response using key words or phrases for each distinct idea. For example, the response, "They helped me feel like I was not alone and that I could count on my peers to help me better understand a concept" (Student G, question 3) has two distinct ideas. The first part of the response, "They helped me feel like I was not alone", was summarized as "not alone." The second part, "I could count on my peers to help me better understand a concept" was summarized as "better understand concept." The summaries were then grouped by common themes. A total of six themes emerged: (1) emotional safety, (2) positive group interaction, (3) negative group interaction, (4) perceived content understanding, (5) instructor approachability, (6) noncontributing factor. A codebook was created for second-round coding. The codebook provided a description, example quotation, and example summaries for all six themes (Table 1). Individual student responses often contained more than one idea related to sense of belonging; therefore, each idea within a response was coded separately.

Theme	Definition	Example	Example Key Word or Phrase Summaries
Emotional Safety	Feelings that contribute to an individual's beliefs that they are able to participate in a group in a positive manner.	"That I am not alone in struggling in somethings." (Student J)	Not judged Safe place Felt heard
Positive group Interaction	Actions that allow group members to work together for a common goal.	"Knowing that my voice is heard or that if i have struggles either my classmates or professor will help me with those." (Student LL)	Working together Common goal Part of a group Work at problems Voice being heard
Negative Group Interaction	The group of students do not interact well together or the interaction is felt to be awkward.	"I feel like they were beneficial with the right people if you were having the right conversations, but, sometimes it was awkward because my classmates did not want to talk." (Student D)	Awkward if didn't want to talk
Perceived content understanding	Contributions to a student's success in the class either through grades or understanding.	"I liked the group quizzes because they would help my grade." (Student BB)	Learning easier Helped in preparing Helped my grade
Instructor Approachability	How easily a student can interact with an instructor or feels that they can interact with an instructor.	"My sense of belonging would mean that the teacher actually does care about the students apart from their school life." (Student JJ)	Teacher cares Matters to professor Accepted by teacher Noticed by teacher
Noncontributing factor	A response that indicates outside factors or the meaning cannot be determined.	"As a student who attends online, I don't have much of a sense of belonging in class." (Student GG)	Online student

Table 1. *Open-response thematic codebook*

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It should be noted that distinctions were made between actions and feelings when overlapping ideas occur across themes. For example, the response "my voice was heard" was coded as positive group interaction to reflect listening as an action. A statement such as "felt that my voice was heard" was coded as emotional safety because the student specifically referenced a feeling attached to having their voice heard.

Student response data from beginning-of- and end-of-course surveys included all six themes when asked, "What does a sense of belonging mean to you in the context of this class?" Initial analysis of the paired data (when available) for the second-round codes revealed that student conceptions about sense of belonging were stable between the beginning- and end-of-course surveys. As a result, only the responses from the end-of-course survey were analyzed for the findings. The third question directly elicited students' perceptions about how cooperative quizzes contributed to a sense of belonging. For this question, five of the six themes were present; only "instructor approachability" was absent.

The findings from this study focus on the four themes present in both open-response questions from the end-of-course survey. Those are: (1) emotional safety, (2) positive group interaction, (3) negative group interaction, and (4) perceived content understanding. The final theme (noncontributing factor) was identified a total of three times between the two questions. Those responses are discussed within another theme when applicable (e.g., the quotation in Table 1 from Student GG)

Results

This study investigated the influence of cooperative quizzes on students' sense of belonging. The findings show that participating in weekly cooperative quizzes positively contributed to students' sense of belonging. The Likert-scale responses for the statement, "The group (cooperative) quizzes contributed to my sense of belonging to this class" (n = 33) showed a strong agreement that cooperative quizzes did contribute to sense of belonging with 27 of the 33 students responding, "very much" or "extremely". Only one student (Student M) responded that cooperative quizzes did not contribute at all to their sense of belonging.

Non-parametric comparisons of Likert-scale belonging scores revealed no significant differences between sections or between the beginning and end of the course. As a result, findings focus on end-of-course survey responses.

The qualitative analysis found that students' answers gravitated toward three predominant themes. Participating in cooperative quizzes contributed to a sense of belonging through the creation of emotional safety and positive group interactions, and promotion of students' perceived content understanding.

Cooperative Quizzes Contributed to Students' Emotional Safety

Students discussed emotional safety as a positive factor that contributed to their sense of belonging. This was often described as being heard by their classmates without judgement. For instance, Student I said, "When participating in group quizzes I feel included and heard by my peers."

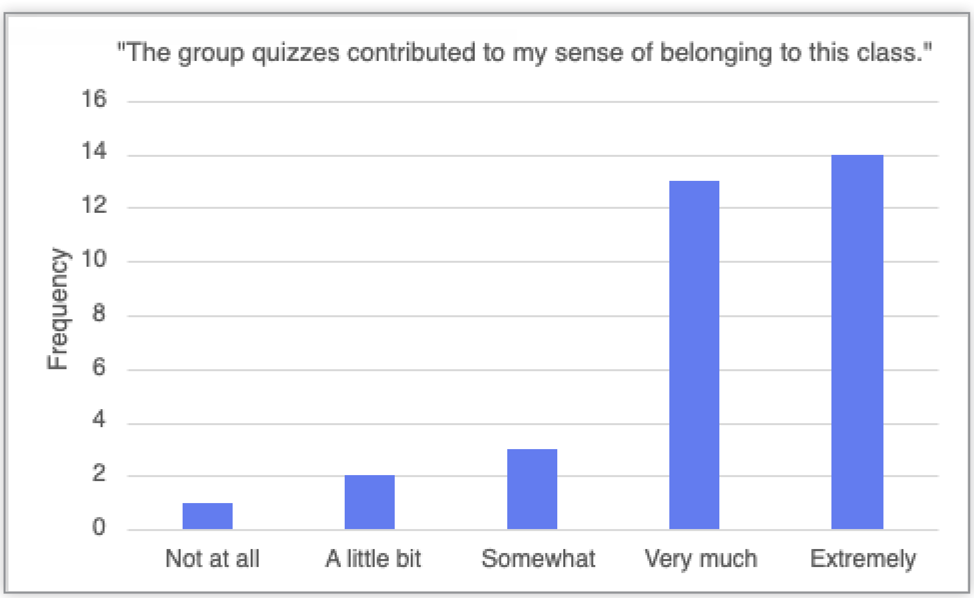

Figure 1. *Frequency of student responses to the statement, "The group quizzes contributed to my sense of belonging to this class".*

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When asked to describe what sense of belonging meant in the context of their A&P class, Student X responded, "Being able to talk and ask questions with open arms." Student W said, "Feeling comfortable and being heard." This student went on to specify that cooperative quizzes contributed to their sense of belonging by, "Interacting with other students and listening to each other and helping one another out and not feeling judged" (Student W). Student G said, "... during group assignments, if you do not know the answers, nobody in the group is making you feel bad." Student EE said, "My input on the group quiz was value[d] and taken into consideration". These responses highlight that feeling valued and not judged were strong components of students' sense of belonging, particularly during cooperative quizzes. Furthermore, there is an underlying indication that fear or anxiety of being judged by classmates prevents students from feeling a sense of belonging.

The theme of emotional safety was also described as being with peers in a positive environment. For example, Student D said they felt a sense of belonging in A&P because, "... you do not feel left out or like you should not be in the class." Student K reported that they experienced a sense of belonging because they "Feel welcome," and Student S said, "Feeling included." Student J emphasized a safe environment during cooperative quizzes because "I am not alone in struggling in something." Student O reported, "In the group quizzes we all worked together…and made sure everyone felt strongly about the answer…so I always felt part of the group." Student J and Student O made a direct connection to cooperative quizzes as a context where they felt emotional safety by being included with their peers. Other responses coded as emotional safety shared similar opinions, with one student (Student U) simplifying saying cooperative quizzes were "amazing" in terms of their sense of belonging.

The quantitative data in the post-survey also suggested the importance of feeling that their opinions were valued for the cultivation of students' sense of belonging. When given the prompt, "I feel that my opinions are valued in this class," student responses saw a median of 4.00 on a 5-point scale (n = 33) with most responses between 4 and 5, highlighting that valued opinions acted as a key indication of their voices being heard, and, by extent, as an indication of their sense of belonging (Figure 2). Moreover, when asked to rate their position on the statement, "I feel like I am a part of the community in this class," student answers revealed a median of 4.00 on a 5-point scale (n = 33), providing support for the importance of inclusion. Together, these results underscore the importance of emotional safety in students' experiences of belonging and its presence within the A&P classroom.

Cooperative Quizzes Impact Sense of Belonging Through Group Interactions

The most frequently identified theme related to students' sense of belonging concerned group interactions.

Positive Group Interactions

The majority of responses coded with this theme (26/29) described the value of positive group interactions by working together on a common goal during cooperative quizzes. For instance, Student A said that the cooperative quizzes contributed to their sense of belonging by "pushing you to interact with your peers and working together to complete

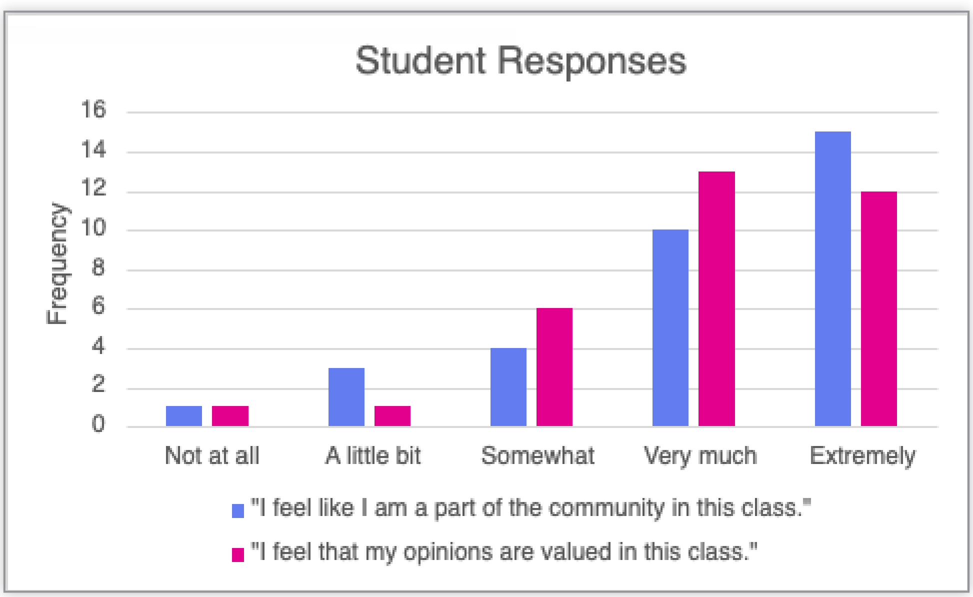

Figure 2. *Frequency of student responses to the statements: "I feel like I am a part of the community in this class" and "I feel that my opinions are valued in this class".*

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a common goal." Student H stated that cooperative quizzes allowed them "...to work together and complete quizzes, and everyone was able to contribute." Student R reported, "[cooperative quizzes] helped connect the other students in the class." Student V explained they felt a sense of belonging during the quizzes because, "...we have time to talk and work out problems." Similar sentiments were repeated throughout the responses related to group interaction. Student GG went a step further to explain that cooperative quizzes were one of the only ways they experienced a sense of belonging as an online student. "I feel as though the group quizzes were one of my only chances to be active in class and with my classmates." Overall, "group interaction" had the highest coding frequency. This suggests a strong relationship between opportunities to problem-solve with classmates on cooperative quizzes and students' sense of belonging.

Responses coded with positive group interactions also echoed subthemes related to emotional safety, such as the ideas of feeling heard and being welcomed. For example, Student C said that a sense of belonging in A&P meant, "My voice being heard." This student went on to explain that the cooperative quizzes contributed to their sense of belonging because, "I felt that I could help others with my opinion." In this example, the positive impact of feeling that their voice is heard during group interactions is amplified by the belief that they are able to use their voice to contribute to their classmates' learning. Student T said they gained a sense of belonging by "...contributing at least a little bit to the class, having the ability to contribute something to my classmates if they need it," reiterating the impact that contributing to the learning environment has on belonging. Similar responses that repeated overlapping themes between emotional safety and positive group interactions commonly used phrases such as "being part" of a group or the class, and "connecting," "discussing," or "communicating" with classmates. Together this evidence creates a strong argument that group work, and cooperative quizzes specifically, has the ability to foster a positive sense of belonging when students have the opportunity to feel included and valued while working towards a common learning goal.

Negative Group Interactions

While the majority of responses were positive, three responses suggested that group interactions could negatively influence students' sense of belonging. For example, Student D said, "I feel like [cooperative quizzes] were beneficial with the right people if you were having the right conversations, but sometimes it was awkward because my classmates did not want to talk." Student GG reinforced their earlier sentiment that, "As an online student, I don't have much of a sense of belonging." This suggests that a lack of group interaction (from learning online) has a negative impact on belonging. However, as quoted earlier, this student felt that participating in cooperative quizzes was a positive source of feeling a sense of belonging.

It should be noted that one student (Student M) responded "nothing" to the question about how cooperative quizzes impacted a sense of belonging. This response was coded as "noncontributing factor." It is the only instance in the open-response data when a student indicated that cooperative quizzes had no impact on their sense of belonging. The paired-data from Student M revealed that Student M was also the one respondent who indicated "not at all" when asked the corresponding question in Likert-scale form (see Figure 1). Therefore, only one of the 33 students who responded to the end-of-course survey did not feel that cooperative quizzes positively impacted their sense of belonging.

Positive group interactions are a key source for developing a positive sense of belonging, and negative group interactions can negatively impact sense of belonging. This suggests that instructors need to foster positive group interactions for cooperative quizzes to successfully contribute to students' sense of belonging. The instructor's role was one of the six themes that emerged during coding. That theme was present in students' responses to the sense of belonging questions but was not present when asked about cooperative quizzes and sense of belonging. The absence is why that theme is not included in the findings. However, the relationship between negative group interactions and sense of belonging suggests that the instructor's role is likely a key factor in creating an overall classroom environment where positive group interactions are possible.

Cooperative Quizzes Influenced Students' Perceived Content Understanding

The final theme explored in this paper revealed that cooperative quizzes not only helped students feel valued and part of a group - they also contributed to students' perceived understanding of the content. When asked how cooperative quizzes contributed to students' sense of belonging, 12 of the 33 responses discussed the positive impact on their perceived learning. This was often reported as the student felt that cooperative quizzes helped their grade, allowed them to learn from peers and compare answers, and/or helped students prepare for individual assessments. References to grades in student comments reflected students' perceptions of learning and success rather than measured changes in academic performance.

For example, Student G said, "[Cooperative quizzes] helped me feel like I was not alone and that I could count on my peers to help me better understand a concept." Student F also reported a positive impact on their understanding. They responded, "I feel like [cooperative quizzes] helped me compare my answers to my classmates and helped me get a different perspective on the questions other than the teacher." Adding on to a response quoted in a previous section, student DD reported that cooperative quizzes "...gave us a chance to… help each other in our learning." In these three examples, the students demonstrated how

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opportunities to develop a deeper understanding of the content positively impacted their overall sense of belonging. In other words, cooperative quizzes contributed to their sense of belonging because it helped them create a better understanding, compare answers, engage with new perspectives, and improve their learning.

Students noted that cooperative quizzes also revealed what they did not know, which enabled students to identify content they still needed to study to prepare for individual assessments. For example, Student Q said, "They helped me realize what I needed to study more on and it allowed me to show what I already knew." Student Y stated that cooperative quizzes "Teach you a lot of stuff that you didn't know before on that topic." Student K reported that "It will prequiz my knowledge of the subject." Each of these examples emphasized the value of cooperative quizzes as a formative assessment that helped the learner evaluate their understanding.

Other students reported, "I liked the group quizzes because they would improve my grade" (Student BB), "Helped to bring my grade up" (Student S), and "Improved my knowledge" (Student L). These opinions were echoed in the remaining responses. The evidence in this theme of perceived content understanding demonstrates that students believe the cooperative quizzes helped them learn from each other and improve their grade(s) which positively contributed to their sense of belonging.

Performance gains were not directly measured in this study, and the qualitative findings reflect students' perceptions of learning rather than measured changes in academic performance. Because the focus of this study was on sense of belonging, students' perceptions of their learning and its impact on their understanding were most important.

Discussion

This research sought to examine whether the use of cooperative quizzes influenced students' sense of belonging. Qualitative themes from students' responses about how cooperative quizzes contributed to students' sense of belonging suggested three main themes. These three themes were emotional safety, positive group interaction, and perceived content understanding.

The theme of emotional safety was similar to Bollen & Hoyle's (1990) feelings of morale, which was related to a sense of belonging. The emergence of the theme of emotional safety, while not suggesting construct equivalence with belonging, shows that students' experiences of belonging often include emotional components such as feeling safe, heard, and accepted. This interpretation is supported by Wilson et al. (2015) who found that positive emotional engagement was associated with a stronger sense of belonging.

The themes of positive group interaction and sense of belonging are tied to studies such as Zumbrunn et al. (2014), who noted that students felt that they belonged because of interpersonal connections with classmates. In this paper these interactions could be positive but students with a low sense of belonging felt their sense of belonging was negatively impacted by their group interactions. Another paper that looked at the interactions that students had during cooperative quizzes was that by Jensen and colleagues (2002). Of the elements noted in this paper that were achieved during cooperative learning, the two that most closely align with the theme of positive group interaction include positive interdependence and small group skills. Both small group skills and positive interdependence can lead to students feeling as if they have had a positive group interaction. Since cooperative quizzes provide a way for students to interact, they can either contribute to positive or negative group interactions and thus either increase or decrease sense of belonging based on the quality of the interactions that students are having during these quizzes.

Rao et al. (2002) and Vazquez-Garcia (2018) both tied the use of cooperative quizzes to better understanding similar to the theme of perceived content understanding in this study. Rao et al. (2002) found that completing the quizzes helped students with understanding and the students rated this as being better than the traditional method of understanding the content. Vazquez-Garcia (2018) found that collaborative group testing improved learning and retention in human A&P courses, the same types of courses that were used in this study.

Instructor approachability was a theme that emerged when asking about sense of belonging at the end of the course but was not identified as a theme mentioned by students when discussing cooperative quizzes. This may be because cooperative quizzes engage primarily student-to-student interaction rather than instructor to student interaction. The instructor noticed during these quizzes that students were more focused on completing the task together and that her role was to ask clarifying questions if the students in the group were stuck.

The structured nature of cooperative quizzes provided repeated opportunities for small-group interaction, which students associated with emotional safety, inclusion, and shared understanding. Even when group membership varied, collaborative discussion appeared to foster opportunities for students to feel heard and supported. These findings suggest that structured, low-stakes collaboration may contribute to perceptions of belonging within the classroom environment.

While many students commented that cooperative quizzes influenced their sense of belonging, one caveat was that it was beneficial when it was with the right people. While

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Student D mentioned that cooperative quizzes "were beneficial with the right people if you were having the right conversations', they later went on to mention that "sometimes it was awkward because my classmates did not want to talk". This might suggest the importance of the instructor in monitoring the dynamics of the group throughout the quizzes to ensure that each member is contributing to the discussion. If many members of the group are hesitant to contribute, cooperative quizzes may become less effective.

The qualitative comments showed that students had an overall positive impression of cooperative quizzes. These positive impressions of cooperative quizzes came when the students perceived that they were able to interact with people in the group that allowed them to be emotionally safe enough to express their ideas. This allowed the cooperative quizzes to contribute to their learning. Not everyone had a positive opinion of cooperative quizzes. If a student didn't want to interact then they might find the group interaction as "awkward".

Limitations of this study included a small sample size due to only three classes being included as well as voluntary participation of students in completing the surveys. Some students that completed the survey at the beginning of the course either withdrew or chose not to complete the survey at the end of the course.

A related concern is whether group scoring could disadvantage high-performing students. Jensen et al. (2002) found that only 10% of students scored worse on the cooperative portion than on the individual portion, suggesting that most students benefitted from or were relatively unaffected by group scoring. Individual accountability was further maintained through larger individual exams, consistent with cooperative learning principles (Jensen et al., 2002). Although this study did not examine grade-level effects of the cooperative quiz structure, the focus was on students' perceptions of belonging rather than measured academic performance.

This study is framed as exploratory rather than causal because several factors beyond cooperative quizzes may have contributed to students' sense of belonging. For example, the relatively high baseline belonging scores at the beginning of the course limit the ability to detect change. Additionally, other classroom elements, including collaborative lab activities and gamified response systems, were present throughout the semester and may have independently influenced students' perceptions of belonging.

Some potential areas of further study might include how much group dynamics, especially the ratio of students that tend to be more extroverted vs introverted, might contribute to the usefulness of cooperative quizzes in helping students learn. If students do not usually contribute to discussions, does the use of cooperative quizzes help them or intimidate them and what role does the instructor have in mitigating this? One strategy that may help mitigate negative group interactions is the use of assigned roles. In this study, the recorder role, the student responsible for writing down the group's answers, rotated among group members across sessions. Expanding this approach to include additional roles such as a discussion facilitator could further promote participation and reduce the awkward dynamics that some students described.

Other potential areas for future research suggested by these limitations might include examining how cooperative quizzes impact academic performance, as this was not part of the present study. Prior research suggests that cooperative quizzes would have minimal impact on high performing students, but this could also be another area of research (Jensen et al., 2002).

Conclusion

This study explored students' perceptions of cooperative quizzes and how they might contribute to their sense of belonging. Overall, the students had a positive view of cooperative quizzes. Since cooperative quizzes can be implemented within a short period of time, they may provide a useful way to introduce collaborative activities and create an academic environment in which students feel they belong.

About the Authors

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Oriented Guided Inquiry Learning (POGIL) within entry-level anatomy and physiology courses. He also works on developing continuing education opportunities for educators who wish to promote inquiry and cooperative group learning within their classrooms. He is the principal investigator for the NSF-funded CAPER project. Emma Prost studies pre-clinical psychology and philosophy at Bishop's University. She is an undergraduate research assistant on the RECAPER grant. Anne Minaki is a pre-clinical psychology undergraduate student at Bishop's University. She is a research assistant on the RECAPER grant.

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Back to TOC

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Enhancing the Pre-Health Curriculum Through a Team-Based Problem-Solving Virtual Cadaver Case Study

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Abstract

A 400-level undergraduate medical physiology course for pre-health students integrated a virtual cadaver case simulation to enhance knowledge of anatomy and physiology, support professional identity formation, and develop competencies outlined by the Association of American Medical Colleges (AAMC). Through a team-based learning activity, students engaged in a clinical case scenario that required application of respiratory anatomy and physiology and introduced pulmonary disease processes within a structured diagnostic decision-making framework. The simulation emphasized collaborative problem-solving, clinical reasoning, and interprofessional awareness. The virtual cadaver case was part of a broader multi-session experience that included additional sessions on pulmonary disease in clinical care, a role-play simulation in a hospital-based simulation lab, and a question-and-answer session with allied healthcare professionals. Students reported enhanced competencies, particularly in teamwork and collaboration, living systems, scientific inquiry, human behavior, and oral communication. Open-ended responses highlighted enjoyable learning experiences, appreciation for teamwork, interdisciplinary collaboration, and motivation to pursue careers in healthcare. This innovation highlights the potential of virtual cadaver simulation to enrich undergraduate pre-health curricula by integrating foundational science with collaborative, inquiry-driven learning. https://doi.org/10.21692/haps.2026.013

Key words: pre-health education, team-based learning, case study, virtual cadaver, Anatomage Table™

Introduction

A team-based problem-solving virtual cadaver (VC) case study was implemented as a simulation activity for students enrolled in a 400-level medical physiology course. The virtual cadaver (VC) technology, the Anatomage Table™ (Anatomage Inc., San Jose, CA), utilizes high-resolution images from real cadavers to create an interactive, computer-based learning platform. In addition to anatomical visualization, the platform includes clinically relevant simulations of physiological functions, diagnostic imaging (CT, MRI), 4D renderings, procedure simulations, and histology (Kavvadia et al., 2023).

The VC case study incorporated the versatile capabilities of the Anatomage Table™ to enhance clinical relevance and context for student learning. This case study was part of a larger simulation activity in which students rotated through two other activities that applied the respiratory anatomy and physiology knowledge from their course to the diagnosis, treatment, and complications of chronic obstructive pulmonary disease (COPD). The other two activities included a role-based high-fidelity mannequin simulation and learning session with physical and occupational therapy on pulmonary rehabilitation. In addition to integrating anatomical and physiological knowledge from their course into a clinically relevant context, the goals of the entire cluster of learning activities were to foster professional identity and motivation for healthcare careers and to introduce the importance of interprofessional collaboration in patient care.

Undergraduate pre-health education typically focuses on foundational biological sciences, but it often lacks clinically relevant experiences and competencies needed to reflect the

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changing medical education landscape (Wasserman et al., 2025). Recent trends in educational research have expanded the use of virtual cadaver technology beyond traditional graduate medical anatomy instruction, extending into undergraduate education across disciplines and assessing broader learning outcomes beyond anatomy knowledge (Kavvadia et al., 2023). Research on both traditional and virtual cadaver learning environments highlights their impact beyond anatomical knowledge, including contributions to professional identity formation and team dynamics (Parker & Randall, 2021). VR-based anatomy education has also been associated with increased student motivation and engagement (Huda et al., 2025), while small-group digital cadaver and traditional cadaver activities have demonstrated effectiveness in supporting collaboration and structured team-based learning (Evans et al., 2024).

At our institution, this approach has been successfully implemented in undergraduate and graduate medical education. Use of the Anatomage Table™ in a nursing pathophysiology course resulted in students' perception of improved integration of anatomy and physiology (A&P) content, enhanced visualization and conceptual understanding, and increased student curiosity and inquiry (Flynn & Lowery, 2025). The graduate-level biomedical science program incorporated student-led curricular design utilizing Anatomage Table™. One particularly significant outcome was a marked increase in students' motivation to learn anatomy, contributing to the development of novel approaches to health sciences andragogy (Coskun et al., 2024).

Materials & Methods

Target Audience

The participants consisted of 15 undergraduate biology students (ages 20-22) enrolled in a 400-level medical physiology course. Students were asked to select all that apply regarding their future healthcare career ambitions. Among the students' future career aspirations were physicians (n=9), physician assistants (n=4), pharmacists (n=2), physical therapists (n=1), and others with write-in "researcher" (n=1).

Materials

The case was conducted using the Anatomage Table™ (Anatomage Inc., Santa Clara, CA; Software Version 11). The worksheet was created using Canva (Canva Pty Ltd., Sydney, Australia). Supplementary materials (e.g., Vector Product Format [VPF] files and worksheet) are available at no cost via the Anatomage Share portal; https://anatomage.com/anatomage-share.

Learning Objectives

Learning objectives guiding the design and implementation of the case study incorporated team-based and problem-based learning theories and the American Association of Premed Competencies (AAMC) (Wasserman et al., 2025).

- Identify key anatomical structures of the respiratory tract and apply them to a patient case study.
- Explain the principles of respiratory physiology and their relevance in diagnosing respiratory diseases.
- Apply principles of AAMC Pre-Health competencies of Teamwork and Collaboration, and Interpersonal Skills by working effectively within a group to assess, diagnose, and discuss treatment considerations for a patient case.
- Apply the AAMC Pre-Health competencies of Scientific Inquiry and Critical Thinking to the medical decision-making process.
- Evaluate clinical data and imaging to support the diagnosis of COPD and lung cancer, integrating anatomical and physiological knowledge into the diagnostic process

Activity Design

The case study design utilized the adult learning theories of team-based learning (TBL) and problem-based learning (PBL). Independently and together, TBL and PBL have demonstrated significant benefits in health science education (Alexander et al., 2024). These pedagogical approaches were selected to promote collaborative problem-solving in complex patient scenarios and to align with the critical thinking skills essential for healthcare professionals. For undergraduate learners, the novelty of virtual cadaver technology and the complexity of diagnostic clinical reasoning tasks created a cognitive challenge that fostered peer interaction and peer learning. The complete case study worksheet is available in Appendix 1. Representative sample images from the worksheet are provided in Figures 1 and 2.

Students worked in teams of 3-4 to diagnose a patient with COPD and metastatic lung cancer. A brief orientation for students included an explanation of the VC operation, an overview of the diagnostic process, and common diagnostic errors, emphasizing the importance of teamwork and the role that diverse perspectives play in combating errors. Students collaborated, guided by the worksheet and with minimal supplemental faculty guidance, through four structured components: navigation instructions for VC technology, clinical case content, foundational clinical reasoning concepts,

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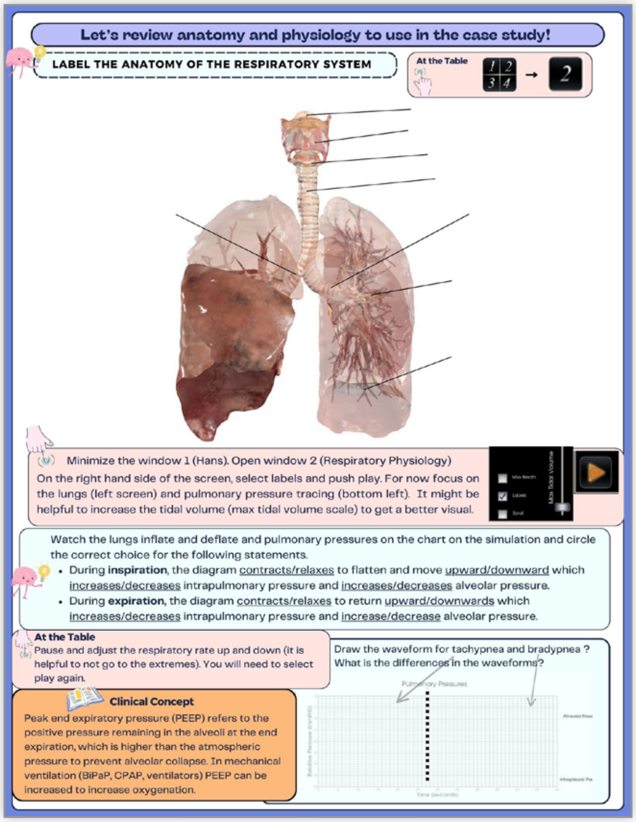

Figure 1. *Example image page 2 of the case-study worksheet. Images used with permission.*

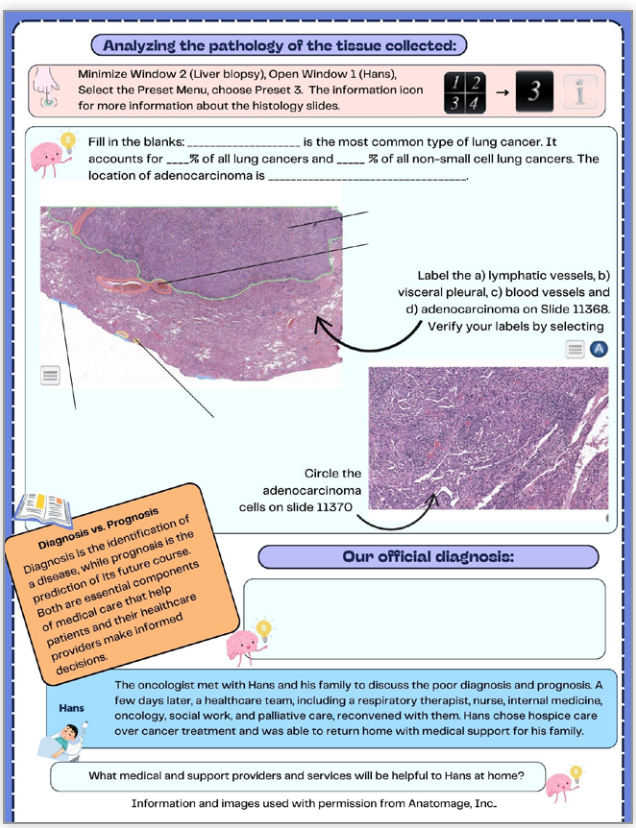

Figure 2. *Example image of page 6 of the case study. Images used with permission.*

and guided group answer writing and discussion prompts. The worksheet uses color coding and icons to align with the four structured components. This activity was completed in 35 minutes; we recommend a duration of 50 minutes to allow more time for peer problem-solving.

Assessment and Evaluation

Assessments of student learning for their course included self-reflection and the submission of case study answers. To assess the learning activities, an anonymous electronic survey was sent via Qualtrics (Provo, UT) within 48 hours of the post-activity, and 15 responses were received. Students rated the activities' impact on the three primary learning goals (professional identity, career motivation, and application of physiological knowledge) and a full list of the AAMC competencies on a five-point scale ('Not at All, Slightly, Moderately, Significantly, and Extremely').

For all three primary learning goals (professional identity, career motivation, and application of physiological knowledge), 66% (n=10/15) of students rated the activities as significantly or extremely impactful, and 87.5% when including moderately impactful. In evaluating AAMC pre-medical competencies, 93% of students rated "Teamwork and Collaboration" and "Living Systems" as having a significant or extreme impact. Other competencies students rated with greater impact were "Scientific Inquiry," "Human Behavior," and "Oral Communication." Open-ended responses revealed increased awareness of healthcare roles and interprofessional collaboration. Students noted an improved understanding of the distinct, yet complementary contributions of healthcare professions, particularly physical therapy and occupational therapy. In one of the learning activities, students strongly recommended the experience to future cohorts, emphasizing the simulation's engaging nature and real-world relevance.

Conclusion

This curricular innovation demonstrates how virtual cadaver technology can extend beyond its traditional role in anatomy instruction to support clinical reasoning, interdisciplinary collaboration, and professional identity development at the undergraduate level. Introducing simulation-based case studies early in the educational pipeline helps bridge foundational science with applied decision-making and provides a scaffold for developing teamwork skills. Aligning these pedagogical approaches with AAMC competencies may enhance motivation and readiness for healthcare training programs and support future curriculum development as competency-based learning and assessment increase in health science education. Pre-health education should consider expanding access to VC technology and integrating interprofessional perspectives to further enrich student learning experiences. Pre-health education should broaden access to virtual cadaver technology and intentionally integrate interprofessional perspectives to enhance students' clinical reasoning, collaborative skills, and engagement with complex healthcare concepts.

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All authors are faculty at Marian University, representing nursing, biology, and physiology across undergraduate and graduate health programs. Maureen Flynn, MSN, CPNP-AC/PC, is an assistant professor in the Leighton School of Nursing and a board-certified pediatric primary and acute care nurse practitioner. Sarah Justice, PhD, is an assistant professor of biology in the College of Arts and Sciences. Trisha Staab, PhD, is an associate professor of biology and Director of the Office of Pre-Medicine and Pre-Health Professions. Robyn Fuchs, PhD, FACSM, FASBMR, is a professor of physiology at the Wood College of Osteopathic Medicine.

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Appendix 1. Complete Case Study Worksheet

DIAGNOSE HANS
VIRTUAL CADAVER CASE STUDY

Hans is a digital cadaver on the Anatomage Table (Table). This is a collaborative team-based case study that includes instructions for operating the Table to explore, learn, and diagnose Hans.

Created by: M. Flynn, MSN, CPNP-AC/PC

Follow the color and icon guide—each one links to tasks in the case!

Hans
Blue boxes have important case study information about Hans.

At the Table
Pink boxes give instructions for navigating the Anatomage Table.

Stop and Think
Light blue boxes ask questions to answer. Use your teammates here!

Clinical Concept
Orange boxes include education to help the tam connect clinical concepts.

Let's get started! The group is treating Hans in the ER:

Hans

Age: 70 Gender: Male Allergies: No Known Drug Allergies (NKDA)
Height: 176.5 cm (5 ft. 8 in) Weight: 46 kg (101.2 lbs)
Vital Signs: BP 102/54 HR: 88 RR: 26 SpO2: 94% on 2L nasal cannula

Hans was transported from the primary care provider (PCP) office to the ER. He was seen for complaints of increasing dyspnea (difficulty breathing) and bloody sputum (hemoptysis). Hans has been smoking since he was 16 years old. He rarely goes to his primary care doctor, denies having other medical conditions, and only takes ibuprofen for chronic back and knee pain. At his PCP, Hans appeared cachectic and his O2 saturation was 86%. He was placed on 2L oxygen via nasal cannula and transported via emergency medical services (EMS). He had a chest X-ray at the PCP's office, but the results and image are unavailable. Per the EMS report, there were decreased lung volumes and a large opacity (more dense area) in the right upper lobe.

Clinical Concept
At room air fracture of inspired oxygen is 21% = Fi O2.21. Supplemental oxygen increases FiO2, 2 L NC is an FiO2 of 28%

Clinical Concept
Medical notes are often written in the format of <u>S</u>ubjective <u>O</u>bjective <u>A</u>ssessment and <u>P</u>lan – **SOAP** notes. This aligns with the medical process of diagnosing a disease called medical-decision making.
Subjective data includes information from the patient's perspective (symptoms, feelings, pain) and objective data consists of measurable, observable facts (vital signs, test results, physical exam findings).

At the Table
Meet Hans (Window 1). Select the Preset Menu and Select Preset 1

1 2 3 4 → 1

Remember the cadaver is 3D/4D and interactive!

You can move the cadaver in all directions and touch the screen reminders of anatomical terms.

The Learning Assistant (magnifying glass) is another helpful tool.

Stop and Think List some key data about Hans case below:

Subjective Data	Objective Data
	How would you describe Hans body composition? Which word in the scenario describes this? What other objective data is consistent with this?

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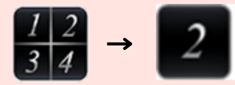
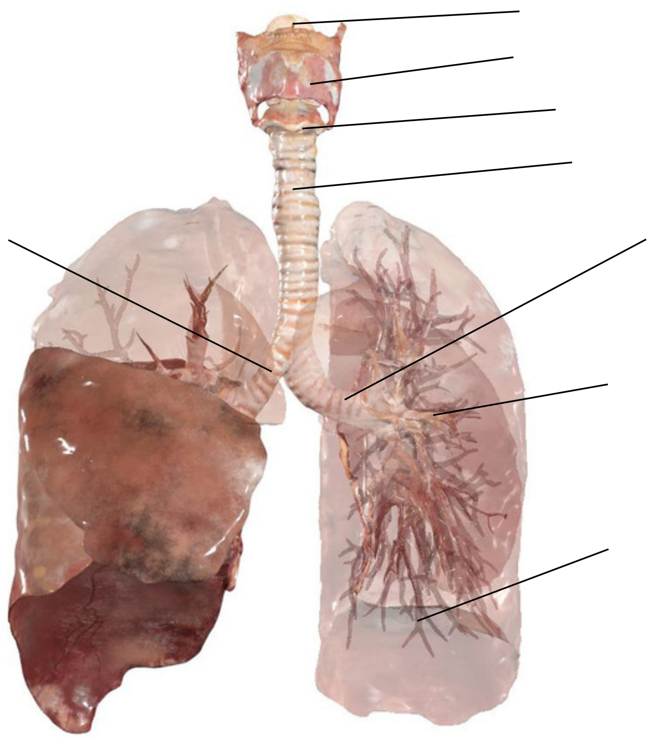
Let's review anatomy and physiology to use in the case study!

LABEL THE ANATOMY OF THE RESPIRATORY SYSTEM

At the Table





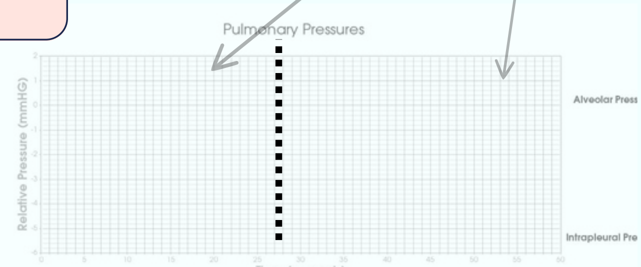
Minimize the window 1 (Hans). Open window 2 (Respiratory Physiology)
On the right hand side of the screen, select labels and push play. For now focus on the lungs (left screen) and pulmonary pressure tracing (bottom left). It might be helpful to increase the tidal volume (max tidal volume scale) to get a better visual.

Watch the lungs inflate and deflate and pulmonary pressures on the chart on the simulation and circle the correct choice for the following statements.

- During **inspiration**, the diagram <u>contracts/relaxes</u> to flatten and move <u>upward/downward</u> which <u>increases/decreases</u> intrapulmonary pressure and <u>increases/decreases</u> alveolar pressure.
- During **expiration,** the diagram <u>contracts/relaxes</u> to return <u>upward/downwards</u> which <u>increases/decreases</u> intrapulmonary pressure and <u>increase/decrease</u> alveolar pressure.

At the Table
Pause and adjust the respiratory rate up and down (it is helpful to not go to the extremes). You will need to select play again.

Draw the waveform for tachypnea and bradypnea ?
What is the differences in the waveforms?



Clinical Concept

Peak end expiratory pressure (PEEP) refers to the positive pressure remaining in the alveoli at the end expiration, which is higher than the atmospheric pressure to prevent alveolar collapse. In mechanical ventilation (BiPaP, CPAP, ventilators) PEEP can be increased to increase oxygenation.

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Spirometry: Measures of Ventilation – Lung volumes and capacities

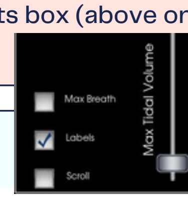
Spirometry is diagnostic test used to assess lung function by measuring the volume of air and how quickly air can be inhaled and exhaled and residual volume in the lungs. Spirometry tests result in number values and in waveforms.

- **Tidal volume (TV) is** the amount of air that is exhaled after passive inspiration, the volume of air going in and out of the lungs at rest.
- **Vital capacity (VC):** is the maximum amount of air that can be moved in and out of the lungs with inhalation and exhalation.
- **Residual volume (RV):** the volume of air that remains in the lungs after maximal inspiration or expiration
- **Total lung capacity (TLC):** the total amount of air in the lungs when they are maximally expanded and is the sum of VC and RV
- **Inspiratory and Expiratory reserve volume (IRV and ERV):** The amount of air inhaled or exhaled during maximum effort (maximum breath)

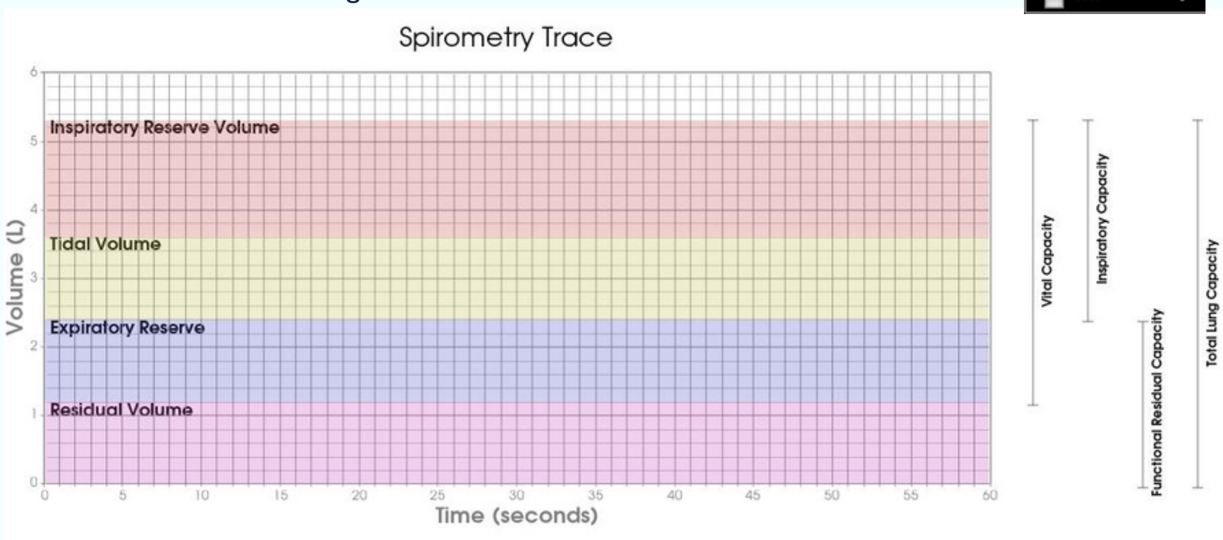
At the Table

Pause the respiratory rate, scroll the tidal volume back to center, and select max breath.

Use the spirometry tracing (bottom right of screen) and the clinical concepts box (above on paper) to answer the following questions.



Draw a few a few of the regular and max breath waveforms::



- What is the term for the amount of air that is inhaled and exhaled during normal quiet breathing?
  - What is the approximate value during normal respiration on the tracing?
- What volumes make up the vital capacity?
  - On maximum breaths what is the volume for vital capacity?
- Discuss: IRV and ERV are decreased in COPD, can you explain why?

While completing a more in depth history, Hans mentions he completed breathing tests for COPD but never got results.

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Back to diagnosing Hans

Problem List vs. Differential Diagnosis

Part of medical decision making involves making a problem list and a differential diagnosis list. A problem list is comprehensive list of medical issues, chronic diseases & conditions, current concerns, symptoms and abnormal findings. A differential diagnosis is a list of potentials diagnoses that are possible for the patient. During the diagnostic process a clinician narrows down these possibilities with the physical exam andpatient history and diagnostic tests.

Add to this problem and differential diagnosis list for Hans:

Problem list	Differential diagnosis
History of smoking Limited primary care Hemoptysis	COPD exacerbation Bleeding disorder

Stop and Think

Discuss with the group: Would a problem list change depending on the setting of healthcare or type of clinician seeing the patient. Why or Why not?

Hans

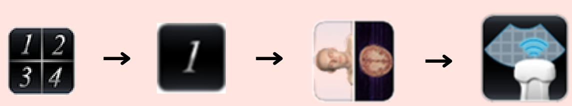
The following diagnostic tests have been ordered: Computed Topography (CT) scan with and without contrast of the chest, abdomen, and brain, Complete blood count (CBC), Complete Metabolic Panel (CMP), and sputum culture.

The hospital is full and there is a long wait for CT scans and lab tests are still pending results. While Hans waits for the CT scan, an ER resident completed a point of care ultrasound (POCUS) in the ER.

Point of **C**are **U**ltrasound – (POCUS) is when a clinical with special training uses ultrasound at the bedside and interprets realtime images to inform clinical decision making.

At the Table

Simulate POCUS on the Table: Minimize Window 2, and Select Window 1 (Hans). Choose the preset menu, and select 1. Open the 3D layout view and choose the ultrasound function.



Move the probe to scant both the lungs and the liver.

Discuss:: What you would say and not say to Hans as you do his POCUS at the bedside? Why might patient communication during POCUS be challenging?

What observations can be made as your scan the patient? Does this change your differential diagnosis or problem list?

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Use the top slider bar to peel back the skin so that the lymphatic system is visible.

Discuss: What do you notice about Hans lymph nodes? What on Hans problem list might have alarmed his primary healthcare team to metastatic cancer?

Metastasis is the spread of cancer cells from the primary tumor to other body parts. Malignant cells invade nearby tissues, enter the bloodstream or lymphatic system, and form secondary tumors in distant organs. This process complicates treatment and is linked to a poorer prognosis. **Common sites for metastatic tumors include the lungs, liver, bones, and brain.**

Hans is able to go to CT scan to get his imaging tests.

We can learn more about this diagnosis by viewing a chest CT scan and its 4D rendering. This patient is a 38-year-old female (not Hans).

Minimize window 1 (Hans), Open window 3 (Case 0784). There is a 4D rendering (left screen) that correlates with a 2D CT scan (right screen). Explore the image by changing the contrast to find the abnormal findings. Presets 1 and 2 contain marker pins.

The information icon offers case study information on this patient's scan.

Write the abnormal finding is each of the numbered pins?

1

2

3

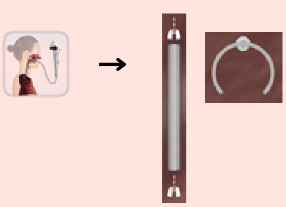
4

Hans's CT scan reveals tumors in the liver, pancreas, and right middle lobe. An inpatient admission order is placed with internal medicine as the primary care team, while oncology and pulmonology are consulted. These orders prompt consultations with the inpatient social worker, palliative care team, physical and occupational therapy, and nutrition services. Oncology, pulmonology, and surgery coordinate a biopsy of the lung and liver tumors in the operating room.

Simulating the biopsy procedures:

Discuss: What is a biopsy? Often a lymph node is biopsied before completing a more invasive procedure – how is a lymph node biopsy helpful?

Biopsy Pulmonary Tumor



Minimize window 3 (Case Study) and open window 2 (Respiratory Physiology). Select the bronchoscopy tool. The left screen shows the anatomical location of the camera, while the right displays the scope view. Use the controls to navigate through the airway; no tumor is present, but bronchoscopy is often used for biopsies!

The differential diagnosis evolves through medical decision-making and patient care. Initially, it focuses on broad categories like cancer, but as more information is gathered, it shifts to specifics, such as determining if lung cancer is primary or metastatic from another site like the liver. There are also several types of lung cancer.

Biopsy Liver tumor

Exit the application, then open a new window for Functional Anatomy and select Injection Procedures. Choose liver biopsy from the menu and position the procedure window in the upper middle of the screen. Follow the 10 procedural steps on the right, with instructions on the left, and remember, the syringe is movable!

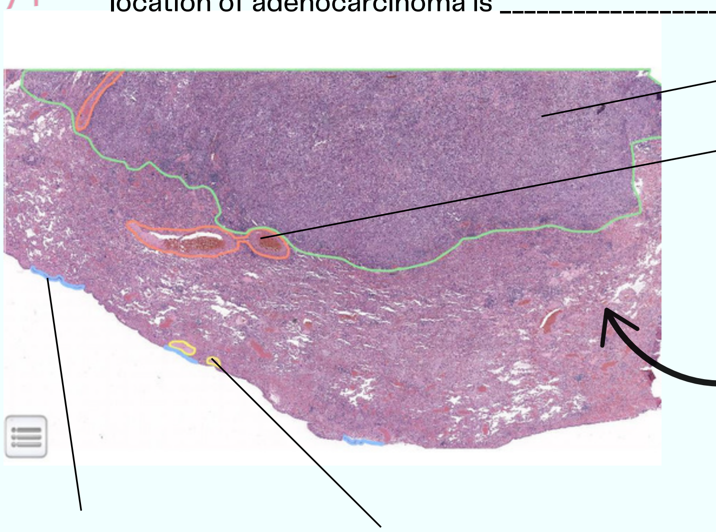
continued on next page

Analyzing the pathology of the tissue collected:

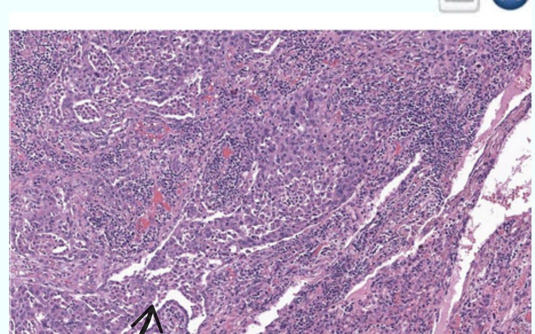
Minimize Window 2 (Liver biopsy), Open Window 1 (Hans), Select the Preset Menu, choose Preset 3. The information icon for more information about the histology slides.

1 2 3 4 → 3

Fill in the blanks: ___________________ is the most common type of lung cancer. It accounts for ____% of all lung cancers and _____ % of all non-small cell lung cancers. The location of adenocarcinoma is _________________________________.



Label the a) lymphatic vessels, b) visceral pleural, c) blood vessels and d) adenocarcinoma on Slide 11368. Verify your labels by selecting



Circle the adenocarcinoma cells on slide 11370

Diagnosis vs. Prognosis

Diagnosis is the identification of a disease, while prognosis is the prediction of its future course. Both are essential components of medical care that help patients and their healthcare providers make informed decisions.

Our official diagnosis:

Hans

The oncologist met with Hans and his family to discuss the poor diagnosis and prognosis. A few days later, a healthcare team, including a respiratory therapist, nurse, internal medicine, oncology, social work, and palliative care, reconvened with them. Hans chose hospice care over cancer treatment and was able to return home with medical support for his family.

What medical and support providers and services will be helpful to Hans at home?

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Back to TOC

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Taking Anatomy to the Library: A Pilot Study of Student Success following Implementation of a Library-Based Anatomy Laboratory

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Abstract

Mastery of human anatomy and physiology course content requires lab time and anatomical structural review. However, limited access to lab spaces and anatomical models due to scheduling constraints creates barriers to student success, as student-centered supplemental learning and physical learning environments have been shown to increase students' perception of course material, support independent learning, and improve academic performance. Campus libraries can facilitate a supplemental learning environment that provides extended access to content-specific space and resources. This pilot project created a supplementary anatomy laboratory space inside the campus library, allowing anatomy students to check out a key to the physical lab space and study anatomical models on their own time during the Spring and Fall 2025 semesters. Of the 98 enrolled students, 13 students checked out the key to the library lab. Students who used the library anatomy lab had higher mean practical exam scores (70.36%; $p = 0.10$) and significantly higher overall course grades (79%; $p = 0.04$). There were no significant correlations between academic rank or major. While practical exam differences were not statistically significant, results suggest a potential association between supplemental learning space and improved course performance in human anatomy and physiology courses. https://doi.org/10.21692/haps.2026.014

Key words: supplemental learning, learning environment, human anatomy and physiology laboratory, undergraduate students

Introduction

Human Anatomy and Physiology is widely recognized as a high-stakes filter course for many students interested in pursuing careers in healthcare (Ellison et al., 2023). Information overload, dense terminology, and visualizing complex three-dimensional relationships contribute to low persistence and high levels of student anxiety. Despite the importance of the laboratory experience in facilitating anatomical understanding, access to physical lab materials tends to be limited to scheduled laboratory times, placing responsibilities on students to master content independently outside of the lab. Restrictive access to lab resources is disadvantageous, because students consistently report a preference for face-to-face laboratory instruction and hands-on access to physical models (Abualadas & Xu, 2023; Anderton et al., 2016; Pettersson et al., 2024).

Direct interaction with physical models enhances spatial reasoning and conceptual understanding, allowing students to manipulate structures and visualize relationships (Wood et al., 2025). Simultaneously, students integrate digital platforms like YouTube, virtual models, and online quizzes to supplement traditional instruction because they have limited access to lab materials (Anderton et al., 2016; Barry et al., 2015; Pettersson et al., 2024). Students turn to digital platforms to improve 3D visualization, revisit concepts, and regulate their learning pace (Barry et al., 2015; Naug et al., 2011; Pettersson et al., 2024). Evidence suggests that combining physical and digital anatomical resources may optimize learning by leveraging the strengths of different learning modalities (Wood et al., 2025). Students demonstrate varied preferences and approaches to studying anatomy; therefore, providing multiple complementary modalities may broaden access and support diverse learners (Tanner & Allen, 2004). Many students state that hands-on learning is their preferred modality (Wood et al., 2025) and this paper examines the outcome of a library space designed to give students access to physical models outside of scheduled lab time.

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Along with instructional modalities, a physical learning environment, or supplemental learning space, influences engagement, learning, and professional identity, specifically in the anatomical sciences (Cleveland & Kvan, 2015; McGarvey et al., 2015; Tanner & Allen, 2004). McGarvey et al. (2015) demonstrated that an anatomy educational space can serve as a positive learning environment. Similarly, Cleveland and Kvan (2015) found that intentionally designed learning spaces in the anatomical sciences influenced student interaction, collaboration, and engagement. Learning environments that support accessibility, flexibility, and peer interaction can extend the benefits from the formal laboratory beyond scheduled sessions in a supplemental learning space (Cleveland & Kvan, 2015; McGarvey et al., 2015).

Campus libraries represent a promising space for supplemental learning, especially in the anatomical sciences. Libraries promote direct and indirect learning with access to resources, areas of collaboration, and private study space which positively influence motivation and productivity (Scoulas & Groote, 2022; Zheng et al., 2024). Higher engagement with library resources has been shown to improve academic performance (Collins & Stone, 2014), but frequency and use alone do not correlate with higher grades. Instead, how students engage with the material and their perceptions of the space are more predictive of student performance (Scoulas, 2021).

Along with perception of the learning space and course material, self-regulated learning is a key predictor of academic success, especially in STEM courses (Abdullah et al., 2020). Student centered, supplemental learning promotes independence and deeper engagement than students who solely rely on faculty led learning in the classroom (Abdullah et al., 2020). Supplemental learning experiences offer flexibility, increase motivation, and reenforce content retention outside of the lab (Anderton et al., 2016; Ellison et al., 2023; Pettersson et al., 2024). Supplemental learning along with a physical learning environment offer an effective way students can reinforce anatomical concepts and increase motivation after attending their traditional laboratory course (Abdullah et al., 2021). Motivation is a significant barrier to student success. A 2024 study of college students in West Virginia identified motivation as the primary obstacle to student success (Henson & George, 2025). Designing learning environments that lower pressure, increase autonomy, and allow flexible access to resources may enhance student motivation and persistence (Schraw et al., 2006). Providing structured supplemental anatomical resources within a library-based learning space may therefore integrate preferred hands-on materials, digital supplementation, peer collaboration, and independent study into a single accessible environment.

Prior research has examined anatomy laboratories, digital tools, active learning interventions, and library engagement independently, few studies have investigated how intentionally designed, course-specific anatomical learning spaces embedded within campus libraries influence student engagement and performance in high-risk STEM courses such as Human Anatomy and Physiology (Anderton et al., 2016; Barry et al., 2015; Cleveland & Kvan, 2015; McGarvey et al., 2015; Pettersson et al., 2024; Tanner & Allen, 2004). To address this gap, this pilot study evaluated the effectiveness of a library-based anatomy lab as a supplemental learning resource for undergraduate students enrolled in Human Anatomy and Physiology Laboratory at a primarily undergraduate teaching institution. This study examined whether the use of the library lab was associated with improved laboratory performance and overall final course grade compared to students who did not use the resource. By providing students with access to anatomical models and study materials beyond scheduled laboratory hours, this pilot study offers preliminary evidence regarding the role of an intentionally designed supplemental learning environments in support of student academic success.

Materials and Methods

The Human Anatomy and Physiology laboratory course is a one-credit, one-semester laboratory course offered as a co-requisite to Human Anatomy and Physiology at a primarily undergraduate teaching institution. This course is typically taken by first year students and fulfills a general education science requirement within the Natural Sciences Department.

The laboratory course meets weekly for two hours across one semester and is offered in multiple sections each term. Instruction focuses on anatomical identification across all eleven body systems using plastic teaching models, pig dissection, and histology. Student performance is assessed through three practical examinations and additional course assignments, culminating in a final laboratory course grade. In spring 2025, a supplemental learning space, the library anatomy lab, was established within a private study room in the campus library. This space contained plastic anatomical models, a microscope with slides, anatomical posters, and flashcards which are typically only accessible in the secured anatomy lab. Students accessed the room by checking out the room key from the library circulation desk for up to three hours per reservation during library operating hours; library operating hours during the spring and fall semesters are Monday-Thursday, 7:30 a.m. - 10:00 p.m., Friday 7:30 a.m. - 4:00 p.m., and Sunday 2:00 p.m. - 10:00 p.m. The room accommodated up to four students at a time. However, only one student was required to reserve the key per session. Students chose to study alone or allow others into the room with them. Library lab usage was defined as at least one recorded key checkout during the semester. Frequency of visits was recorded but was not included in analysis due to

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low subgroup size. Nine students used the lab once, three used it twice, and only one student used it four times. Access to the library lab was voluntary and available throughout the Spring and Fall 2025 semesters. Students were notified of this resource through course announcements on Blackboard learning management system and verbal reminders during lecture and lab sessions.

This pilot study is a retrospective comparative design, including all students enrolled in the Human Anatomy and Physiology Laboratory course during the Spring 2025 and Fall 2025 semesters. Students were categorized into students who used the library lab (checked out the key) and students who did not. Students' academic ranks and majors were recorded.

Laboratory practical exam scores and final course grades were compared between library lab users and students who did not use the library lab (non-users). Practical exam scores and overall scores were compared by an independent t-test assuming unequal variances. Academic year, major and course performance were compared using multivariate analysis of variance (MANOVA). This project was approved by the Institutional Review Board of Fairmont State University and qualified for Exempt status Category 1. All data were de-identified prior to analysis.

Results

A total of 98 students completed the Human Anatomy and Physiology Lab course during 2025. The majority were freshmen ($n = 43$) or sophomores ($n = 26$), with nursing majors comprising 71% of the cohort ($n = 70$) (Tables 1, 2).

Of the 98 students in the course, 13 students (13.3%) utilized the library anatomy lab at least once during the semester, with four students visiting more than once. No statistically significant differences in academic rank or major were observed between library users and non-users, suggesting a baseline of academic characteristics between groups ($p > 0.05$) (Tables 1-3).

Academic Rank	Non-library group	Library group
Freshman	38	5
Sophomore	23	3
Junior	9	1
Senior	15	4
Total	85	13

Table 1. *Academic rank of students in the 2025 cohort.*

Major	Non-Library group	Library group
Nursing (BS, AS, pathway)	63	7
Biology	4	0
Chemistry	2	1
Forensic Science	1	0
Exercise Science	2	1
Psychology	3	1
Occupational safety	3	1
Engineering (BS, AS)	2	0
Criminal Justice	2	0
Community health	1	1
AP health professionals	0	1
AA interdisciplinary	1	0
Business administration	1	0
Total	85	13

Table 2. *Majors of the students in the 2025 cohort.*

	Wilks' Lambda	F	df	Error df	p-value
Academic rank & overall grade	0.9808	0.9305	2	95	0.3979
Academic rank & practical average	0.9801	0.9641	2	95	0.385
Major & overall grade	0.9583	2.066	2	95	0.1324
Major & practical average	0.9558	2.194	2	95	0.1171

Table 3. *Multivariate analysis comparing library and non-library users by major and academic rank.*

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Students who used the library lab demonstrated higher mean practical exam scores (70.36% SD 14.75) compared to non-users (64.06% SD 21.02), a 9.37% percent difference (Fig. 1). However, this difference was not statistically significant ($p = 0.10$), and effect size was small to moderate (Cohen's $d = 0.31$), indicating limited practical but not statistically supported differences in performance. Five students who used the library lab failed one or more of their practical exams while ten students who did not use the library lab scored > 90% on one or more of their practical exams.

Conversely, overall final laboratory grades were higher in the library group (79.35% SD 9.07) compared to the non-library group (72.44% SD 19.2), a 9.10% difference and were significantly higher among library users ($p = 0.042$) (Fig. 1). Effect size was small to moderate Cohen's d (0.38), suggesting a modest association between library lab use and overall course performance. Two students who used the library lab did not pass the course (overall grade < 70%) and 14 students who did not use the library lab had > 90% for their overall lab grade contributing to the variability in the dataset and reducing the strength of observed effects. While statistically significant differences were observed in overall course grade, small effect sizes were present indicating that observed differences should be interpreted cautiously in the context of a pilot study.

Discussion

This pilot study examined whether a structured, library-based anatomy lab was associated with improved student performance in a Human Anatomy and Physiology laboratory course at a primarily undergraduate teaching institution. Although the sample of students who used the library lab was small ($n = 13$), these users demonstrated higher mean practical scores (70.36% SD 14.75) and significantly higher overall lab grade (79.35% SD 9.07) compared to non-users (64.06% SD 21.02 and 72.44% 19.21, respectively). Though mean practical exam scores were not statistically different, and effect size was small to moderate, the results suggest a limited but potentially meaningful association between use of the supplemental learning space and educational impact. These findings support the feasibility of embedding course-specific anatomical resources within a campus library setting (Pettersson et al., 2024).

The performance differences between students who used the library resource and the students who did not may reflect multiple interacting factors. Access to anatomical models outside of scheduled laboratory time provides supplemental learning tools and additional time for review, reinforcement, and content mastery (Anderton et al., 2016; Ellison et al., 2023; Pettersson et al., 2024). These students are also given the opportunity to exercise low-stakes, self-directed learning, which is strongly associated with increased student success (Abdulla et al., 2020). Because the library space allowed small groups to study simultaneously, it could potentially facilitate informal, peer-led instruction, which has been shown to enhance student learning (Ellison et al., 2023). However, this study was not able to track group usage or peer interaction within the space.

The small effect sizes observed (Cohen's $d = 0.31$-0.38) suggest that while differences between groups exist, they are small to modest. This pilot study offers a limited sample size ($n = 98$) with only 13 students in the library group. These results act as a preliminary indicator of a potential association warranting further investigation.

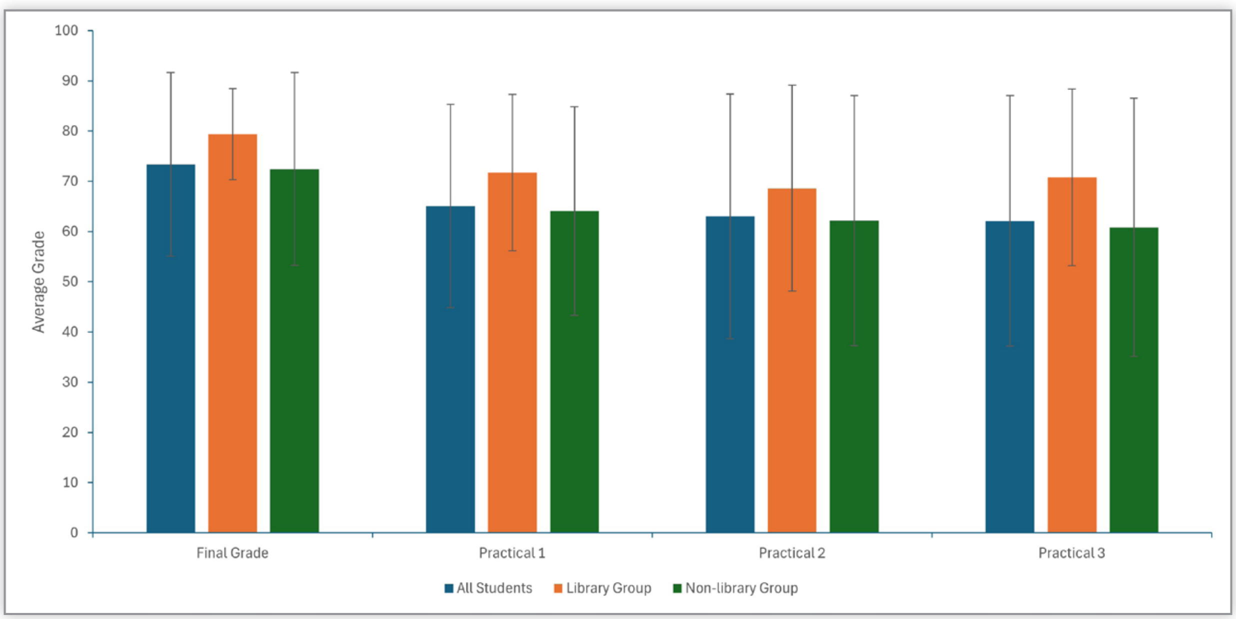

Figure 1. *Average final grade and practical exam grades of students in the Human Anatomy and Physiology Laboratory course during the Spring and Fall 2025 year.*

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Several limitations should be considered. First, this pilot study represents a small sample size (n = 98), but the institution is also small (n = 3,500). The small sample size limited statistical power. Second, lab use is voluntary. Self-selection bias is likely present, as students who chose to use the library lab resources may have been more motivated or academically engaged (Scoulas & Groote, 2022; Zheng et al., 2024). Third, there is only one key to the anatomy lab, limiting precise measurement of individual and groups utilizing the space simultaneously. Prior research suggests that how students interact with academic resources is a better predictor of performance (Scoulas, 2021).

In addition, this study did not account for all confounding variables that may have influenced student performance. This includes the student's prior anatomical knowledge or total study time or methods implemented beyond the library lab. These factors could contribute to variability in performance. Future research should incorporate these variables. This study also highlights structural and logistical considerations that may influence usage rates. Requiring students to request a physical key from library staff may have introduced an access barrier. Finally, many students at this institution balance full- or part-time employment while maintaining full-time academic enrollment (Henson & George, 2025), potentially limiting time available for optional supplemental study.

Despite these limitations, this pilot study contributes to preliminary evidence supporting the role of an intentionally designed, course-specific learning environment housed within a campus library. Consistent with Collins and Stone's (2014) findings that academic resource use correlates with student performance, this study suggests that supplemental access to anatomical materials outside of scheduled lab time supports improved course performance on practical examinations and final grade in Human Anatomy and Physiology. Along with increasing student performance, this anatomy study space within the campus library required no financial investment, leveraging existing institutional resources and supplies.

This pilot study was designed to evaluate feasibility rather than effectiveness. Future work should expand this research through multiple years to improve statistical power and assess longitudinal trends. The next phase of this study would benefit from incorporating a student survey to understand motivations for library lab use or non-use, level of prior anatomical knowledge, and study behaviors outside of the classroom. Future research should incorporate electronic ID card access to more accurately track individual and group usage of the room and reduce potential access barriers. Collecting longitudinal usage data will allow for more robust analyses of the relationship between library lab utilization and academic performance. Continuing to increase awareness of the space may also enhance participation as students who successfully use the space share it with new students.

In conclusion, while larger and more controlled studies are needed to determine causal relationships, this pilot demonstrates the feasibility of a library-based anatomy lab and suggests that supplemental, accessible anatomical learning environments are a promising strategy for supporting student success in high-risk STEM courses.

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About the Authors

Dr. Kristy Henson has been teaching undergraduate and graduate human anatomy and physiology courses for 10 years and one year respectively. Dr. Kristen Winter has been teaching undergraduate and graduate human anatomy and physiology courses for 10 years and five years respectively. Derek Nuzum is a librarian supporting communities of learners for 8 years. Jacquelynn Sherman has been an academic librarian supporting learning and scholarship for 15 years.

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Back to TOC

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Unlocking Student Engagement: A Classroom Escape Room in Renal Physiology and Pharmacology

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Abstract

This paper describes the design and implementation of a classroom escape room activity developed for a second-year undergraduate course in physiology and pharmacology. The escape room was intended as an innovative active learning strategy to reinforce course concepts through collaborative, problem-based engagement. Students worked in small groups to solve a series of puzzles focused on topics in renal physiology and pharmacology. The escape room offered several advantages in that it provided a clinically oriented, applied review of course material, fostered teamwork and communication, and generated strong classroom engagement. Moving forward, we plan to adapt the escape room format for other courses in our department. While this iteration was implemented as a teaching innovation, future offerings may be formally evaluated with appropriate research ethics approval. Overall, the escape room format demonstrates promise as a flexible, engaging, and clinically relevant active learning strategy for students in STEM fields. https://doi.org/10.21692/haps.2026.015

Key words: escape room, renal system, physiology, pharmacology, learning activity

Course Overview and Delivery

Physiology and Pharmacology 2000: The introduction to the Integration of Physiology and Pharmacology is a unique second-year undergraduate course that combines human physiology and pharmacology into a single, integrative curriculum. The course is team-taught by multiple instructors from both disciplines, an approach that exposes students to a broader range of expertise and teaching styles. Such team teaching in an integrated course has been advocated in medical education to reduce knowledge overload and encourage students to develop critical thinking skills (Active learning in large class settings, 1995). The course is delivered in a traditional stationary lecture hall setting with approximately 200 students in attendance. Teaching a class of this size presents challenges for engagement as large lectures can encourage passivity, and it is inherently more difficult to implement interactive methods in a big room (Bennal et al., 2016). Nonetheless, the course deliberately interweaves active learning activities into the lecture schedule to complement didactic instruction and keep students engaged.

Each week, students attend lectures covering core concepts in physiology (e.g., cardiovascular, renal, respiratory systems) alongside related pharmacology (e.g., drug mechanisms and treatments for those systems). The content is structured around integrative learning outcomes that align with Bloom's taxonomy and the core concepts in physiology (Michael et al., 2020), progressing from foundational knowledge to higher-order thinking. In practice, this means students must first remember and understand key concepts, then apply and analyze them in novel contexts. Examples include predicting drug effects on physiological pathways, rather than stopping at rote memorization, or identifying the core concepts in action as we progress through different physiological systems. This deliberate design reflects the modern shift in science education from mastering factual breadth to developing deeper reasoning and problem-solving skills (Carrasco-Gomez et al., 2023). By framing outcomes in Bloom's cognitive levels, the course encourages students to move beyond recall and into application and analysis, once a base of knowledge is established. Physiology and Pharmacology 2000's assessment scheme balances formative and summative evaluations.

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A hallmark of Physiology and Pharmacology 2000 is its use of active learning strategies to reinforce lecture material. Recognizing that purely passive lectures can leave students unengaged, the course embeds low-stakes, formative learning activities both during and between lectures. These activities, which include student-generated concept maps, case-based learning scenarios, and infographic projects, as examples, are designed to help students actively process and integrate physiology and pharmacology content. In addition to the active learning tasks described, students complete four exams throughout the year, spaced roughly per one-quarter of the course (e.g., after nervous system, after cardiovascular/renal, etc.), with the last exam being cumulative. These exams are a mix of knowledge recall and application questions, leading to a higher number of application questions as the year progresses. The integration of physiology and pharmacology is emphasized in exam questions (for example, asking how a particular drug's mechanism would affect a physiological feedback loop). By the time an exam arrives, students have repeatedly engaged with the material via active learning exercises, which is expected to improve their performance. In fact, active learning in class has been correlated with better exam outcomes in undergraduate physiology.

Active learning Strategies in a Large Classroom

Active learning strategies have consistently been shown to improve student performance, particularly in science, technology, engineering, and mathematics (STEM) fields (Freeman et al., 2014; Prince, 2004). Within this broad pedagogical framework, gamification (i.e., using game elements to enhance learning) has gained popularity as a means to increase engagement and motivation. One specific form of gamification, the educational escape room, has emerged as a creative approach to encourage collaboration, critical thinking, and applied problem-solving. Systematic reviews highlight escape rooms as effective across disciplines for promoting teamwork and deep learning (Fotaris and Mastoras, 2019; Taraldsen et al., 2020). In health sciences education, escape rooms have been successfully adapted to contexts ranging from nursing (Gómez-Urquiza et al., 2019) to pharmacy (Cain, 2019; Eukel et al., 2017) and surgical training (Kinio et al., 2019). These studies collectively suggest that escape rooms are not only engaging, but also versatile tools for reinforcing discipline-specific knowledge and skills.

Building on this literature, we designed and implemented an escape room activity focused on renal physiology and pharmacology for second-year undergraduate students. A study by Carrasco-Gomez et al. (2023) implemented a series of peer-led escape room challenges (more on this below) in a large physiology course and found that students who participated scored significantly higher on final evaluations than those who did not. Likewise, other active-learning interventions in large enrollment science courses have demonstrated improved grades and comprehension compared to lecture-only formats (Hu et al., 2024). Thus, the combination of formative in-class activities and periodic summative exams in Physiology and Pharmacology 2000 is grounded in pedagogical research supporting better knowledge retention and understanding through active engagement (Meneses-Monroy et al., 2023).

What We Did

In an effort to introduce an engaging form of active learning into our course, we developed an in-class "escape room" centered on renal physiology and pharmacology (Appendix 1). This exercise was designed to reinforce course content through collaborative problem-solving, while providing students with opportunities to apply theoretical concepts in a more applied, case-like context. The activity took place during a regularly scheduled lecture session. Students were instructed to form small groups of three to four, and each group was provided with a set of puzzles at the beginning of class. Unlike commercial escape rooms, where participants physically progress through stages, our classroom version was structured around intellectual progression. Groups were required to solve the first puzzle before presenting their answer to the instructor or teaching assistants to receive a clue to begin the next puzzle. This cycle continued until all puzzles were solved, culminating in a final passcode that symbolically allowed students to "escape."

Puzzles were carefully aligned with learning outcomes for the renal module of the course, with each puzzle requiring students to draw on both conceptual understanding and problem-solving skills. Of note, individual puzzle prompts integrated multiple learning outcomes from both disciplines of the course (i.e., physiology and pharmacology), while further emphasizing real-life scenarios seen in clinical practice. By sequencing puzzles in this way, we ensured that students had to engage actively with both the physiology and pharmacology content to progress through the assignment.

This structure also intentionally mirrored the type of layered reasoning that students are expected to develop for healthcare professions, where integration of core knowledge is required to make informed patient care decisions. Like the other learning activities in the course, this was a low stakes assessment. Answers were imputed into Gradescope, an online marking software that allows students to upload their answers and submit as a group as they progressed through the escape room. The course TAs then marked the answers after the activity was completed. The escape room thus functioned not only as a review exercise, but also as a scaffold toward more clinically oriented thinking.

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Advantages of the Escape Room (What Worked Well)

This escape room format offered several pedagogical advantages. Foremost, it allowed students to apply knowledge in ways that extended beyond rote recall. Because most of our students intend to pursue professional programs such as medicine or dentistry, the clinical orientation of puzzles provided relevance to future career paths. Previous literature on active learning emphasizes the importance of situating material in authentic contexts, as this fosters deeper engagement and promotes knowledge transfer (Freeman et al., 2014; Prince, 2004). With that in mind, our escape room aligned with well-established evidence supporting student-centered, applied learning activities.

The collaborative design also mirrored real-world healthcare environments where teamwork and communication are essential. Groups were required to reach consensus before submitting answers, which encouraged peer teaching and discussion. Anecdotally, the classroom atmosphere was lively and focused, with students actively debating possible answers and engaging enthusiastically with the material.

From a logistical perspective, the activity benefitted from the presence of two teaching assistants in addition to the instructor. This additional support allowed us to distribute clues and provide guidance efficiently. For a class of approximately 200 students, having multiple facilitators was critical to maintaining flow and minimizing bottlenecks in student progression.

Another notable advantage was the role of generative AI in the design process. While the puzzles themselves were refined by the instructor, initial prompts and ideas were generated with the assistance of AI tools such as ChatGPT (https://chatgpt.com/). This streamlined the creative process considerably, enabling rapid prototyping of puzzle formats and scenarios. Although still in its early stages of educational integration, generative AI has the potential to serve as a valuable tool for instructors developing innovative, content-specific activities. Importantly, its use here illustrates how instructors can harness such tools as starting points, while maintaining responsibility for accuracy, alignment with learning objectives, and appropriateness for the student population.

Overall, the escape room successfully promoted active engagement, offered a novel and enjoyable change of pace, and encouraged students to apply their knowledge in meaningful ways.

Disadvantages of the Escape Room (What Did Not Work Well)

Despite the successes of our escape room, the activity was not without challenges. One of the most significant issues concerned accessibility for students requiring accommodations. For example, some students may have accommodations in place requiring extra time for completion of the assignment. While extra time may not be necessary, this situation highlights the difficulty of addressing accessibility considerations without prior notice. Active learning assessments such as escape rooms can inadvertently introduce barriers for students with learning or processing accommodations, particularly when activities are time-bound. Future iterations will require more deliberate planning to ensure equitable participation, such as offering extended time options or alternative puzzle formats.

Another challenge emerged because the activity template was posted on the course learning management system earlier in the day. Some students had already attempted, and in some cases, completed, the first puzzle before the start of class. This diminished the intended sense of discovery and may have created inequities between students who had previewed the material and those who had not. In the future, careful control over the timing of the activity release will be necessary to preserve integrity of the escape room.

Instruction clarity also proved to be a small source of difficulty. Some groups did not follow the specified directions for puzzles, possibly due to misinterpretation or ambiguity. Others bypassed the intended clues, instead inputting answers they believed to be correct without engaging with the underlying reasoning. While this is not uncommon in game-based activities, where students often seek shortcuts to “win”, it raised questions about whether all groups achieved the intended learning outcomes. The experience highlighted the importance of clarity in instructions and the need to design puzzles that cannot easily be circumvented without mastering the relevant material.

Further, the scale of the class presented inherent logistical challenges. With approximately 200 students, the activity relied heavily on the assistance of teaching assistants. Without their help, it would have been difficult to manage clue distribution and respond to questions in real time. This raises concerns about scalability for instructors teaching large classes without similar levels of support. While escape rooms are engaging, their practical implementation may be constrained by staffing resources.

Finally, as this activity was implemented as a teaching innovation rather than a formal research study, ethics approval was not obtained to survey students or analyze test score outcomes. As a result, the impact of the escape room on student learning cannot be reported for this iteration.

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Future Applications

Despite these limitations, the escape room holds considerable promise for broader use in STEM education. We plan to adapt this activity for our first-year human physiology course for nursing students, where it will be delivered during synchronous tutorials. In this setting, smaller class sizes of approximately 50 students are likely to alleviate some of the logistical difficulties encountered in our larger course. This next iteration will focus on endocrine physiology, offering students the chance to work through puzzles related to hormonal regulation, feedback loops, and endocrine disorders in clinical practice. Beyond our own courses, the escape room model could be extended to medical or dental education, where applied reasoning and clinical integration are even more central. In these contexts, puzzles could be designed around case-based scenarios requiring students to synthesize physiology, pharmacology, and pathology to arrive at diagnostic or treatment decisions. Escape rooms also lend themselves to interprofessional education, where mixed groups of students from different programs could work together, mirroring collaborative healthcare environments (Hu et al., 2024).

The activity also opens opportunities for future scholarship of teaching and learning. While this iteration was implemented primarily as a teaching innovation, subsequent offerings could be studied more formally with appropriate research ethics approval. Questions worth exploring include: Do escape rooms improve knowledge retention relative to traditional review methods? How do they influence student engagement, motivation, or confidence in applying material? To what extent do accessibility adaptations affect student experiences? Rigorous evaluation of these questions would contribute to the growing literature on gamification and active learning in higher education.

Conclusions

Our experience implementing an escape room in a second-year physiology and pharmacology course demonstrates both the promise and the challenges of gamified active learning in higher education. The activity successfully engaged students, fostered collaboration, and encouraged applied reasoning within clinically relevant contexts. It also highlighted logistical considerations, particularly around accessibility, instructions, and scalability.

These insights underscore a broader point in that innovative activities (such as escape rooms) should be seen not as one-size-fits-all, but as adaptable frameworks requiring thoughtful design and ongoing refinement. Instructors seeking to adopt similar approaches must consider not only content alignment, but also the diverse needs of their student populations and the resources available to them.

Looking ahead, the escape room format holds substantial potential for STEM education across disciplines. With further development and systematic evaluation, it may serve as a valuable pedagogical tool for enhancing student engagement, deepening conceptual understanding, and preparing learners for the complex, collaborative decision-making environments.

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Appendix 1. Active Learning Assignment: Renal Physiology Escape Room

(Answer key is in red)

This 'escape room' consists of four puzzles. Complete each puzzle to unlock a clue that will allow you to progress to the next puzzle. Solve the final challenge to escape!

Puzzle #1— Diagnose the Dysfunction

For each of the following clinical scenarios, identify whether there will be an **increase** or **decrease** in **glomerular filtration rate (GFR)**. Once you have an answer for each case, retrieve your next clue from your TA!

a) A patient presents with low urine output, normal blood pressure, and no signs of infection. You discover that they recently took a high dose of NSAIDs (e.g., Advil), which caused constriction of the afferent arteriole. What is the net effect on GFR? __ *decreased*___

b) A patient reports abdomen pain and blood in their urine. Imaging reveals a kidney stone lodged in the ureter, and lab tests show increased hydrostatic capsular pressure (P_{BC}). What is the net effect on GFR? ________*decreased*_______

c) You discover that a patient has protein in their urine. Lab work suggests reduced colloid osmotic pressure of glomerular capillaries (π_{GC}) and hypoalbuminemia (reduced albumin in the plasma). What is the net effect on GFR?___*increased*________

d) An athlete is admitted to the hospital after running a marathon in extreme heat. They are severely dehydrated, reporting dizziness, low urine output, and muscle cramps. Their blood pressure is 88/55 mmHg, and blood tests show elevated serum creatinine levels. What is the net effect on GFR? ________*decreased*_______

Puzzle #2— Totally Tubular Detective

Oh no! Your nephrons have lost their ability to properly reabsorb and secrete substances. For each of the transporters on your clue sheet, fill in the chart below. The first row has been completed for you as an example. Once complete, grab your next clue from your TA! Chart is below.

Transporter	Section of Tubule	Substrate(s)	Direction of transport & renal process	Hormonally regulated? (Yes/No)
Sodium-Hydrogen exchanger	*Proximal tubule*	*Sodium and hydrogen*	*Sodium→ from filtrate into tubule cell (reabsorption)* *Hydrogen→ from tubule cell into filtrate (secretion)*	*Yes→ angiotensin II*
SGLT symporter	*Proximal tubule*	*Glucose*	*From filtrate into tubule cell (reabsorption)*	*No*
Aquaporin II	*Collecting duct*	*Water*	*From filtrate into tubule cell (reabsorption)*	*Yes→ Antidiuretic hormone*
Organic Anion Transporter 3 (OAT3)	*Proximal tubule*	*Anionic drugs/solutes*	*From blood into tubule cell (secretion)*	*No*
Sodium-Calcium Exchanger	*Distal convoluted tubule*	*Sodium and calcium*	*Sodium: from blood into tubule cell (secretion)* *Calcium: from tubule cell into blood (reabsorption)*	*No*
NKCC symporter	*Ascending LOH*	*Sodium, potassium, chloride*	*From filtrate into tubule cell (reabsorption)*	*No*

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Puzzle #3— Creatinine Conundrum

Your patient comes in for some routine bloodwork, part of which involves assessing kidney function via estimated glomerular filtration rate (eGFR). Using the lab results provided on your clue sheet, calculate the patient's estimated urinary concentration of creatinine.

$$eGFR = \frac{[Creatinine_{urine}] \times urine\ volume}{[Creatinine_{plasma}]}$$

$$178\ L/day = \frac{[Creatinine_{urine}] \times 3.4\ L/day}{2.15\ mg/L}$$

$$[Creatinine_{urine}] = 112.56\ mg/L$$

Puzzle #4— Operation Homeostasis

For each of the patients below, assign one of the interventions on your clue sheet to 'cure' them of their renal impairment. Once you have completed each of the four patient assignments, retrieve your final passcode from a TA!

a) Patient #1:

- Symptoms: high blood pressure, high serum Na^+
- Intervention: *Prescribe ACE inhibitor*

b) Patient #2:

- Symptoms: cardiac arrhythmia, high serum K^+, low urine volume
- Intervention: *Prescribe loop diuretic*

c) Patient #3:

- Symptoms: low blood pressure, low urine volume, high urine osmolarity
- Intervention: *Administer IV fluids*

d) Patient #4:

- Symptoms: low serum K^+, edema, low urine volume
- Intervention: *Prescribe aldosterone receptor antagonist*

Final passcode: *Homeostasis restored*

continued on next page

Clues

The following are the clues students are given after each puzzle is complete. Students are given a little slip of paper or shown the clues and they can copy them down.

Puzzle 2 clue: Each item fills in the next line in the first column of the chart.

1. SGLT symporter
2. Aquaporin II
3. Organic Anion Transporter 3 (OAT3)
4. Na+/Ca2+ exchanger
5. NKCC symporter

Puzzle 3 clue: Student will be given the blood work results after they have completed the chart:

Blood work results:

Patient: Lilah Brown

Age: 34

Date of Birth: 1991-01-27

Date of Service: 2025-02-14

TEST	RESULT
Hematology	
White blood cells	5.8 x 10^9 cells/L
Red blood cells	5.43 x 10^{12} cells/L
Hemoglobin	152 g/L
Hematocrit	0.453 L/L
Platelet count	283 x 10^9 cells/L
General Chemistry	
Glucose, fasting	5.4 mmol/L
Sodium	141 mmol/L
Potassium	4.0 mmol/L
Serum creatinine	2.15 mg/L
eGFR	178 L/day
24 h urine output	3.4 L/day

Puzzle 4 clue: Students are given these four treatment options that they then use to fill in the blacks for puzzle 4.

- Administer IV fluids
- Prescribe ACE inhibitor
- Prescribe aldosterone receptor antagonist
- Prescribe loop diuretic

Once they have completed puzzle 4, they can 'unlock' the final passcode, which is 'Homeostasis restored'.

Back to TOC

PERSPECTIVES ON TEACHING

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Anatomy Laboratory In-Reach to Engage Pre-Health Professions Students

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Abstract

Human gross anatomy laboratories (GALs) have been used to host outreach events to promote an interest in healthcare careers. However, these events have largely targeted high school students, not necessarily those already pursuing coursework toward degrees and careers in these fields. Therefore, we developed an in-reach event using our GAL specifically for pre-health undergraduate students at George Washington University to provide an opportunity that reinforces their career desires using the anatomical sciences. We set up different stations for student rotations based on anatomical regions supporting discussions of clinically relevant anatomy. We have outlined a stepwise process, detailing our experiences and improvements over the past three years. Improvements in that time have included a formal evaluation and the addition of a central nervous system station. Our event is comparable to outreach events for planning logistics, staffing, advertising and communication, and content coverage. While response rates were low, pooled post-event survey data from 2024 and 2025 indicated that respondents enjoyed the experience (09.8%; n= 80) and noted that it reinforced their desires to pursue healthcare careers (98.8%; n= 80), aligning it with outreach reports. We hope our experience can serve as a guide for others to use a GAL for similar in-reach events. https://doi.org/10.21692/haps.2026.016

Key words: anatomy education, healthcare careers, undergraduate students, pre-health professions, educational outreach

Introduction

Outreach events have played a key role in increasing interest in pursuing a career in healthcare for decades. Initially, this focus was centered around increasing enrollment of underrepresented groups in medicine (Association of American Medical Colleges, 1970). Early versions of these programs, like Phillips and Wile's (1990) 6-week Health Careers Enhancement Program for Minorities at Case Western Reserve University School of Medicine, included a mix of activities such as mentor pairing, research opportunities, and clinical exposure to provide underrepresented students with exposure to the health professions fields. Their program also exhibited significant growth from 22 attendees in 1989 to over 180 by 1990, indicating an increased interest for underrepresented groups in medicine. Over the years, the original concept of outreach programs has continued to evolve with the addition of pathway programs. Mason et al. (2024) defined outreach versus pathway programs as separate, but related entities. Pathway or pipeline programs, they argued, have an objective goal to specifically help underrepresented students reach matriculation in a health science career. In contrast, outreach programs represent broader community engagement for attendees with relevant and health-related educational topics and resources.

More recently, outreach events that utilize a gross anatomy laboratory (GAL) have been used to engage the community and raise interest in healthcare professions. There are a number of publications exploring the importance of hosting outreach events in a GAL (e.g., Meyer et al., 2018; Redway et al., 2023). The major goal of these programs has been to increase interest in healthcare or science careers, primarily in high school student populations, using GAL activities and whole-body donors. Mason et al. (2024) provided brief descriptions for two GAL-oriented outreach programs that included high school students as attendees: the University of Nebraska Medical Center (UNMC) High School Alliance and the West Virginia School of Medicine (WVUSOM) Anatomy

continued on next page

Lab Educational Program. Both programs leveraged the unique resources of the GAL and whole-body donors to immerse students in professional-level health sciences educational experiences for future careers.

At The Ohio State University (OSU), the outreach event for high school students used a station-based format with whole-body donors and isolated healthy and pathological specimens to engage attendees (Redway et al., 2023). Meyer et al. (2018) hosted both high school and undergraduate students at the University of Mississippi Medical Center (UMMC). Like the events at OSU, UMMC had several stations through which students rotated, each focusing on a different organ system. All visiting students, regardless of academic level, were currently enrolled in an anatomy and physiology (A&P) course and this opportunity provided them with a hands-on, engaging environment to enhance their learning.

A key component of outreach events is the reported impact attendance had on the attendees' plan to pursue healthcare careers and/or degrees in STEM. Redway et al. (2023) provided post event survey data demonstrating that 50% of respondents planned to pursue a career in healthcare or science. Similarly, another study found that 84% of the students visiting the GAL planned to pursue an advanced degree in STEM or the health sciences (Mathis et al., 2020). Despite a handful of studies stating that their outreach experiences increased visitors' interest in pursuing a career in healthcare, one study did not. Ruth et al. (2023) found no significant change in interest in the healthcare field, but they did find a significant increase in the visitors' interests in human anatomy. Despite these findings, the body of literature provides evidence to support that GAL outreach activities benefit attendees by providing enriching educational experiences and may stimulate interest in future healthcare careers.

To date, the literature has mostly discussed events that bring students external to the institution into the GAL, as opposed to students currently enrolled at the institution. Therefore, we refer to the former category as outreach events, emphasizing the external reach and community engagement. In contrast, we refer to the latter as 'in-reach events," emphasizing the internal reach and engagement within one's institution. Moreover, there is limited information on whether these in-reach events included dedicated pre-health professional students or organizations. To our knowledge, three reports come closest to this in-reach definition.

Mathis et al. (2020) brought undergraduate students enrolled in an A&P course from their main campus to a GAL event at their health sciences campus. However, these students were not specifically part of dedicated group planning to pursue health sciences. The program described by Ruth et al. (2023) required attendees to have been part of a course focused on human anatomy, a pre-health professions club, or a group affiliated with a health professions degree program. While this included college students, most attendees (88.9%) were in high school. The authors did not separate evaluation data for those in high school versus college, limiting our ability to extrapolate to an event focused on pre-selected health professions students. While the WVSOM Anatomy Lab Educational Program included students in allied health programs, there was no information regarding demographics or whether the attendees were part of a dedicated pre-health professions student organization (Mason et al., 2024).

However, pre-health professions students are an ideal group for GAL in-reach events because they are actively considering those next steps (*e.g.*, graduate degrees, post-graduate training) for healthcare careers. Therefore, as gross anatomy teaching faculty at George Washington University (GWU), we collaborated with undergraduate pre-health professions student organization leaders to develop the GWUGAL In-Reach Event to promote and encourage their desire to pursue careers in the health sciences. Our first goal in this manuscript was to compare our three-year GWUGAL In-Reach Event with the existing outreach events in relation to event planning and execution. Our second goal was to compare the results of our in-reach event for reinforcing healthcare career interest among self-identified pre-health students with the existing literature on outreach events for promoting healthcare careers more broadly.

Methods

We have organized the overall planning and execution of our in-reach event into five steps. Major actions for each step are summarized in Table 1 for ease of reference. Details for the quality improvement steps are provided in the subsequent sections.

Step 1: Identifying Event Attendees

Implementation of an in-reach event requires coordinating with those groups of students who are interested in healthcare careers. This step is equivalent to recommendations presented by Knippenberg et al. (2020) for identifying institutional resources and identifying community partners for outreach events. For us, our partners and attendees were members of the GWU American Medical Physiology Club (AMPC).

The AMPC is composed of students who have the explicit goal of becoming future healthcare workers. The AMPC, which includes 951 members in its listserv as of 2025, advertises itself as a "pre-health community" (GW Engage, n.d.), but does not have information regarding specific majors or careers for its members. Because the AMPC is student-run, we unfortunately have no additional details besides that these are current undergraduate students. Nonetheless, these students have all self-selected to pursue healthcare careers. An added benefit of working with enrolled students is the elimination of costs associated with logistics (*e.g.*, food, transportation), which may be necessary for working with external K-12 student groups (Mason et al., 2024; Meyer et al., 2018; Redway et al., 2023).

continued on next page

Steps	Actions Taken
Step 1: Identify event attendees	• Determine relevant student groups and campus partners • Reach out to gauge interest • Discuss the logistics of the event (e.g., what to expect, what the event will entail) with student groups
Step 2: Planning the event	• Determine planning time necessary to organize event • Confirm facilitator volunteers • Select event date • Determine number of attendees that can be hosted • Determine event timing • Determine resources needed
Step 3: Advertise the event	• Select advertising strategy (in coordination with campus partners) • Determine sign-up process • Distribute relevant information (e.g., PPE) to send to attendees prior to event
Step 4: Host the event	• Outline event timing • Select teaching materials • Pre-brief with facilitators prior to event • Welcome attendees to event • Provide overview of logistics such as GAL space, resources, and event flow • Move attendees through event and stations as necessary
Step 5: Evaluate the event	• Thank attendees and facilitators • Review evaluation format with attendees • Distribute evaluation following event • Use evaluation data to plan for event next year

Table 1. *Planning Steps and Actions for the GAL In-reach Event*

Step 2: Planning the Event

The planning process for hosting in-reach events is critical and ours has had several critical changes to optimize the event and make it run smoothly (Table 2). Planning was first initiated in February 2023 between the faculty organizer and the Department of Anatomy and Cell Biology's (A&CB) undergraduate gross anatomy course director (M.S.) and AMPC leadership. While a two-month planning time for an April event was feasible, if the event was to become an annual occurrence, all parties preferred to initiate the process earlier in subsequent years. Therefore, planning time for the event was increased to four months for an event to be offered annually in April. Additionally, we tried to plan the in-reach event when there was limited activity in the GAL (*e.g.*, medical GAL sessions). Although we could not limit the total activity in the GAL over the week, we always scheduled the event during normal operating hours in order to appropriately account for staff and faculty hours. More importantly, the event date was aligned well with the undergraduate campus schedule, ensuring AMPC student availability.

Another reason to increase the amount of time to plan for the event is to ensure facilitator availability, given that schedules associated with the various academic courses and programs with which we are involved often fill up rapidly (see below for our definition of "facilitator"). The faculty organizer sent an email to gauge interest and availability to potential facilitators, including preferred dates to have the event. We prefer a date in April when there is general lull in GAL usage and faculty obligations.

The A&CB faculty also have experience in developing and running similar prosection-based outreach events for GWU students, family, and friends, with up to 200 participants, such as our biennial "A Day in the Life." In this event, family and/or partners of current medical students attend events that simulate typical experiences a student has during their time in medical school at GWU. This includes an anatomy lab experience in which groups attended one of several hour-long sessions in the GAL, where they rotated through a variety of anatomical stations. This is similar to the one we are describing here, so setting up and running this type of event was something with which we were already familiar, further easing the planning process. Therefore, we did not need to devote significant planning time every month for our planning purposes for the in-reach event.

Selecting donors and prosected specimens (*e.g.,* isolated organs, limbs) was not difficult because the faculty continually use these specimens throughout the academic year. In all the courses and programs in which A&CB faculty participate, we use a range of techniques within the GAL involving whole-body donors and prosections. As such, there was no need to set up a designated time to evaluate current inventory.

continued on next page

	2023	2024	2025
Date of event	April 14th, 2023	April 5th, 2024	April 25th, 2025
Available time for planning event	2 months	Increased to 4 months	No change
Medical labs scheduled in GAL during week of event	Yes	No	Yes
Number of attendees	150 (capped)	No change	No change
Number of sessions (50 attendees per session)	3	No change	No change
Facilitators	3	Increased by 3	No change
Attendee: facilitator ratio	17:1	Decreased to 8:1	No change
Total time for sessions	1.25 hours	No change	1.5 hours
Number of stations	4 (Abdomen, Lower Limb, Thorax, Upper Limb)	No change	5 (Abdomen, Lower Limb, Thorax, Upper Limb, Central Nervous System)
Post-event evaluation	No	Yes	Yes

Table 2. *Improvements to the GAL In-reach Event from 2023 to 2025*

The second improvement is related to increased staffing at our event. We employed facilitators, faculty and teaching assistants (TAs), who volunteered to participate in the in-reach event. The TAs serve as instructors in our medical gross anatomy laboratory sessions and desire additional teaching exposure for their future careers. The faculty also teach gross anatomy in our undergraduate, graduate, health science, and medical programs. Initially given the overall space of the GAL, we decided to cap attendance at 150 students. To rotate all students through the GAL, we divided attendees into three groups of 50. Due to the limited planning time in 2023, we had only three facilitators resulting in an attendee to facilitator ratio of 17:1. In 2024, we increased the number of facilitators to six, resulting in an attendee to facilitator ratio of 8:1. This increase was due to advanced planning, allowing us to confirm more faculty and TA volunteers.

The final improvements in the event relate to the total time for the sessions and the content of the stations within each session. With three groups of 50 attendees in the lab, we determined each session would need approximately 1.25 hours. In 2023 and 2024, each attendee rotated through four, 15-minute stations that contained whole-body donors and prosections of the abdomen, lower limb, thorax, and upper limb. We utilized donors and prosected specimens from previous courses to reduce costs associated with preparing new teaching materials. As noted above, this also minimized the planning process because we already have a running inventory of donors and prosections that would be appropriate for this type of event.

Based on attendee feedback, we added a central nervous station in 2025. To keep the 15-minute timing for the stations, we lengthened the overall session time to 1.5 hours to accommodate the additional station (see Step 4 below).

Step 3: Advertising the Event and Its Logistics

Determining how to advertise the event with potential attendees is crucial to the success of an in-reach event. Advertisements for our in-reach events were made with the coordination of the AMPC leadership and faculty organizer (M.S.). Once the event logistics and facilitators were confirmed, the faculty organizer shared a Google Sheet with the AMPC to distribute through their listserv with the event information. This step was critical because the faculty organizer did not have access to the email listserv. Students were instructed in the email to sign up for one of the three sessions on a first-come, first-serve basis.

We also used the AMPC listserv, via the AMPC leadership, to communicate with registered attendees. The faculty organizer drafted an email with the AMPC leadership to share with all registered attendees several days before the event. The email and associated documents included GWU GAL-specific logistical information (*e.g.*, when to arrive), dress requirements (*e.g.*, closed-toed shoes, long pants, GAL-provided personal protective equipment (PPE)), and specifics about safety precautions. All attendees were required to read over the GAL safety rules and regulations and sign a GWU-specific waiver and assumption-of-risk form. The email also emphasized the emotional impact of the experience and normalized the range of reactions (*e.g.*, fear, anxiety, excitement) to the GAL and donors.

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Step 4: Hosting the Event

With proper planning and communication established, we outlined our GAL in-reach events from 9am to 3pm to accommodate the three 1.25- or 1.5-hour sessions (Appendix 1). The total time included breaks for facilitators. The faculty organizers and GAL staff selected the whole-body donors and prosections at least one day prior to the event to ensure materials and numbers of donors were adequate for the number of attendees. Donors were selected to represent a range of dissection approaches (*e.g.*, superficial vs. deep) and for presence of clinical conditions (*e.g.*, hernia, knee arthroplasty). During a 0.5-hour period immediately prior to the event, facilitators met to pre-brief and outlined expectations for the sessions. Station assignments (*i.e.*, regions of the body) were assigned to facilitators by area of interest.

At the beginning of each session, facilitators walked attendees through donning the correct PPE. PPE was provided at no cost because it was already included in the standard operating budget of the GAL. The event organizer then provided an overview and orientation to the GAL as well as introduced each of the facilitators and staff members present and described their respective roles not only for the event, but also at GWU, including our respective roles in the undergraduate, graduate, medical and healthcare professional curricula. He discussed the flow of the event, reviewed the stations and their respective content, and indicated how attendees would rotate through the GAL. Following a brief discussion of the laboratory setup and review of safety expectations, the faculty organizer provided an overview of the importance of respect and comportment for the donors and their families and loved ones, followed by a moment of silence. This was done, not only to emphasize the unique opportunity and gift provided for the educational experience, but to recognize the emotional impact of the setting.

After the introductory comments, attendees were divided into smaller groups of 10-12 students to rotate among different anatomical region stations: abdomen, lower limb, thorax, upper limb, and (2025 only) central nervous system (Table 3, Figure 1). Facilitators then uncovered the donors to expose areas that were relevant for teaching at that station. During instruction, facilitators focused on three major topics: 1) engagement with the station's material and discussion of the general gross anatomy, 2) relevance of the materials to common clinical conditions, some of which were noted with the donors, and 3) general discussion of the anatomical sciences and the A&CB's courses and programs (time permitting). This format mirrored the framework described by Meyer et al. (2018) prioritizing experiential learning and emphasizing clinical relevance. Facilitators varied in the amount of time allocated to each topic, though the general flow was to talk about the anatomy first (structures, muscles, neurovasculature) followed by associated functionally and clinically relevant injuries, disorders, and diseases. Facilitators encouraged the attendees to ask questions and to interact with the donors as much or as little as they wanted, given their personal comfort with this way of learning.

Station	Learning Objectives	Donor Materials	Clinical Correlations
Abdomen	• Describe the structure, function, blood supply, and innervation of structures in the abdomen/pelvis regions • Discuss the anatomical basis for clinical conditions of the abdomen	• Four full-body donors with in situ viscera and vasculature • Two prosections with abdominal wall and inguinal canal • Isolated kidneys and livers (pathologic and normal)	Hernias, hydronephrosis, kidney stones, liver carcinoma, gallstones
Lower Limb	• Describe the muscles, ligaments, actions, and neurovasculature of the lower limb • Discuss the anatomical basis of common injuries of the lower limb	• One full body donor prone for gluteal region and posterior thigh (hamstrings) • One full body donor supine for anterior thigh (quadriceps) • Isolated knees, including knee replacements • Isolated lower limbs for leg and foot regions	Knee ligament injuries, knee replacements, ankle sprains, sciatica
Thorax	• Describe the structure, function, blood supply, and innervation of structures in the thorax • Discuss the anatomical basis for clinical conditions of the thorax	• Two full-body donors for thoracic wall, heart and lungs in situ, and mediastinum • Isolated hearts and lungs (pathologic and normal)	Pacemakers, coronary bypasses, cardiomegaly, thoracocenteses,
Upper Limb	• Describe the muscles, ligaments, actions, and neurovasculature of the upper limb • Discuss the anatomical basis of common injuries of the upper limb	• Two full-body donors, both supine; shoulder joint partially exposed • Isolated upper limb prosections for posterior arm, shoulder/rotator cuff, posterior forearm, and hand	Rotator cuff tears, shoulder separations, shoulder dislocations, brachial plexus injuries (e.g., lower trunk palsies)
Central Nervous System (2025 only)	• Describe the major external structures, internal structures, and coverings of the brain and spinal cord • Discuss the neuroanatomical basis of diseases and disorders of the central nervous system	• Full body donor with laminectomy • Isolated brains for externally visible structures • Isolated brain slices for internal grey and white matter and ventricles	Cerebrovascular accidents, motor disorders (e.g., Parkinson's) spinal cord injuries, hydrocephalus

Table 3. *Description of stations, donors and materials used, and clinical correlations.*

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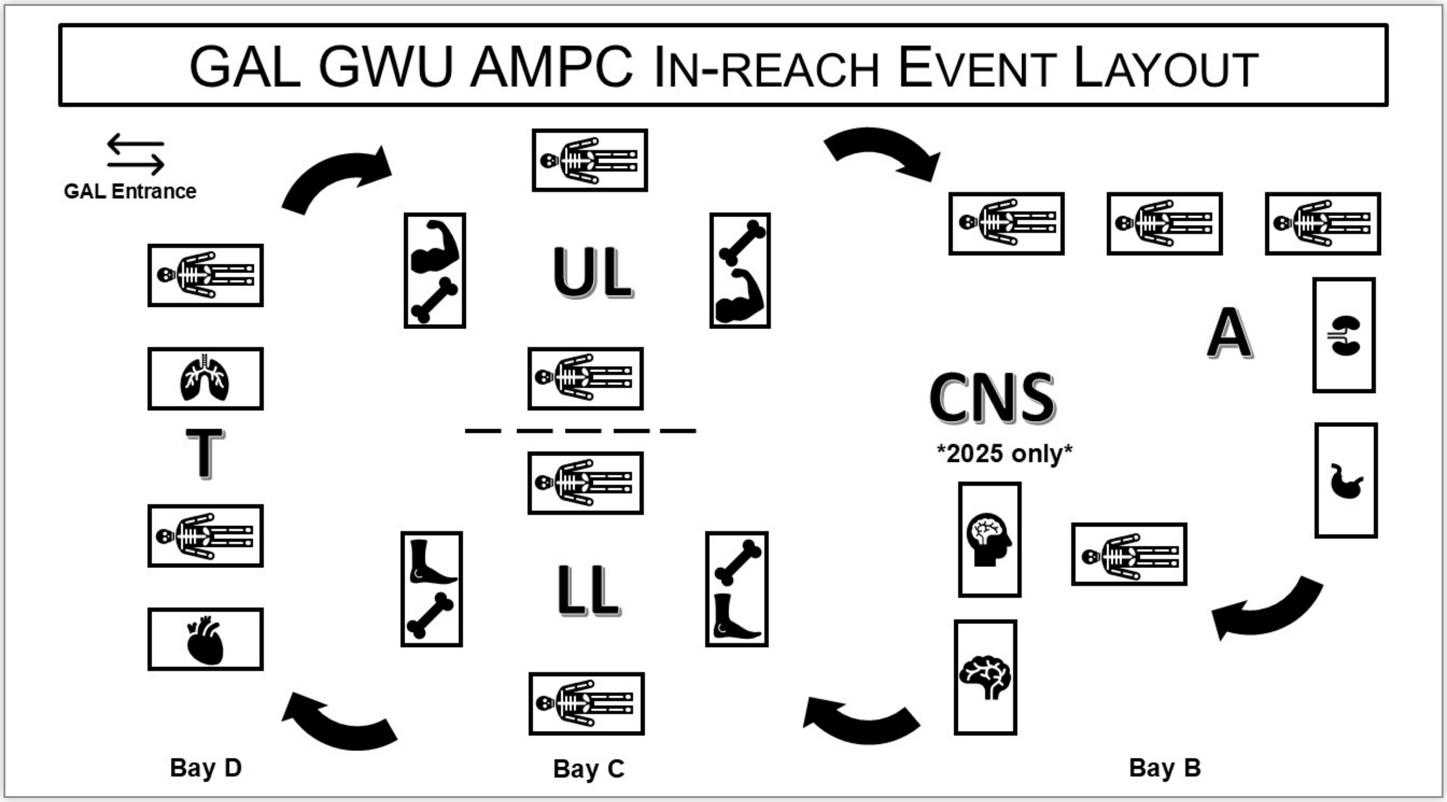

Figure 1. *Schematic of the in-reach event layout. Students were evenly distributed among several stations: thorax (T), upper limb (UL), abdomen (A), central nervous system (CNS, 2025 only), lower limb (LL). Arrows indicate the direction of flow from one station to the next after a 15-minute period. Body icons denote full-body donors and body part icons denote isolated specimens. Dashed line indicates separation between UL and LL stations.*

The attendees had 15 minutes at each station to discuss the anatomical region with the facilitator. Overall movement throughout the laboratory during the event was in a circular manner to ease the directional flow of student groups (Figure 1). Facilitators and staff members were also able to direct the groups if there was any confusion.

Following the final rotation, all the attendees and facilitators regrouped for closing comments. The faculty organizer thanked the facilitators for their efforts and the attendees for their participation and comportment. Collectively, the facilitators answered any general questions that attendees had. We also saw this as a potential opportunity to advertise and discuss our departmental-based anatomy courses, including our Human Anatomy Minor program that encompasses four A&CB courses.

Step 5: Evaluating the Event

Establishing a more formal process for evaluating in-reach events is our final recommended step. While we did not have an established process in 2023, we added an evaluation form for general quality assurances purposes in 2024. Following each of the three sessions, the faculty organizer announced that we would be sending out a Google Forms survey as part of our evaluation procedure to determine how well the event was received and what, if any, improvements could be made for future events. The in-reach event and our survey were considered quality improvement by the institutional review board and therefore did not need to undergo submission to the Office of Human Research. The faculty organizer designed the survey and asked attendees to rate their satisfaction with the overall event, logistics, relevance of the event to future careers, and interest in enrolling in the departmental Human Anatomy Minor. Free response sections allowed respondents to share any additional thoughts regarding logistics and the overall event. The 2025 survey added questions about attendees' majors, interest in pursuing biomedical graduate degrees, and awareness of the Minor. These modifications also represent the ongoing quality improvement efforts of the event year after year. The surveys were completely anonymous and voluntary. The survey links were open for three weeks following the events. The AMPC leadership sent reminders to complete the surveys until they were closed.

Survey data were exported to Microsoft Excel (version 16, Microsoft Corp., Redmond, WA), tabulated, and frequency calculations were made. Free response comments were organized and assigned to categories based on the responses. Comments were assigned for categories to allow for frequency calculations as described by Redway et al. (2023).

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Results

Quantitative Data

We received a total of 47 responses from the post-event survey in 2024 and 34 responses in 2025, yielding response rates of 31.3% and 22.7%, respectively. Data are separated by event year in Appendix 2 while pooled data are presented below. Survey data indicated that most attendees (n = 73; 90.1%) were pursuing a pre-health track. Most respondents (n = 80; 98.8%) indicated that the event was important or very important to their future career. All respondents indicated that they were likely or extremely likely to recommend a similar event in the future. Almost all respondents (n = 80; 98.8%) were satisfied or extremely satisfied with the event. More specifically, most respondents were satisfied or extremely satisfied with the introduction to the GAL and donors (n = 78; 73.1%), station content (n = 79; 97.5%), flow between stations (n = 78; 73.1%), timing at each station (n = 71; 87.7%), and closing remarks (n = 79; 97.5%). While only three respondents (3.7%) were registered for the Human Anatomy Minor, thirty-four respondents (42.0%) indicated that they were likely or extremely likely to enroll in the minor after attending the event.

Survey data from 2025 provided additional information not included in the 2024 survey. Most respondents (n = 29; 85.3%) were pursuing or planning to pursue degrees in biology, public health, and neuroscience and half of respondents (n = 17) were interested in pursuing a biomedical graduate degree. The addition of the central nervous system station was well received, with all respondents satisfied or extremely satisfied with the station's content. While only one student (2.9%) was enrolled in the minor, most respondents (n = 14; 70.6%) were aware of it.

Free Responses

We received a total of 24 free responses in 2024 and 13 responses in 2025. Comments are separated by event year in Appendix 3 while pooled data are presented below. Free response data (n = 16) demonstrated overall support for the event and the educational opportunity it provided. Comments (n = 6) also indicated satisfaction with the general setup and logistics of the event, with one respondent highlighting how the 2025 event had more engagement with facilitators. Students are not prohibited from attending the event for multiple years, so this comment was an unintended benefit for our internal evaluation. Comments (n = 2) also emphasized the importance of the event for future healthcare careers and in helping attendees decide to pursue pre-health majors.

Although limited by the number of responses, we also identified areas of improvement. In 2024, respondents suggested additional content (*e.g.*, central nervous system) to be added for the 2025 event. Four comments wanted either longer or shorter time periods for each station. There was a concern by one respondent that the information provided before the event and during the introductory remarks should be more specific, namely a better description of the appearance of the whole-body donors (*e.g.*, general appearance, color).

Finally, there were comments that were related to the Human Anatomy Minor. While one respondent indicated an increased inclination to register for the Human Anatomy Minor, other respondents identified challenges with registering for the minor, particularly scheduling challenges, or an inability to add an additional one. These were specific to 2024 only.

Discussion

Our first goal was to compare our in-reach event to the broader outreach literature in terms of planning and execution. Our in-reach event had both similarities and differences compared to existing outreach formats described in the literature. Our stepwise process mirrored recommendations by Knippenberg et al.'s (2020) to embed sustainability for outreach events. The largest difference between our in-reach event and outreach events was our focus on pre-health students versus outreach to the K-12 audiences. However, several studies have included combined educational levels that encompass undergraduate and high school students. These studies have been limited by specific demographic or recruitment information (Mason et al., 2024; Meyer et al., 2018) or an overwhelming representation of high school students (Ruth et al., 2023). While Mathis et al. (2020) described an in-reach event, it did not include dedicated group planning to pursue health sciences, as these attendees were identified from their enrollment in anatomy & physiology courses.

Our planning process, including the improvements made over the past several years, exhibited similarities and differences with the outreach literature. While many reports do not provide specific details regarding planning and scheduling (*e.g.*, Mathis et al., 2020; Meyer et al., 2018; Ruth et al., 2023), the large-scale outreach event organized by Redway et al. (2023) detailed a planning timeline of around four to five months, similar to our event. Although event planning information was lacking, most reports were specific in detailing the overall event timing and number of attendees.

When examining the total time for the laboratory portion of the events, outreach efforts ranged from one hour (Ruth et al., 2023) to upwards of six hours (Redway et al., 2023). While the former event was only one hour, they offered the event 30-40 times during a calendar year, reaching between 450–750 students. The event created by Mathis et al. (2021) was two hours in length for 99 students but offered only a single time. In contrast, our event was similar in duration to the large-scale event described by Redway et al. (2023), although we completed ours in one day, not two. We also

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had half as many attendees (n=150) compared to the large-scale outreach event. Additionally further expansion of our event to include attendees beyond AMPC (e.g., other majors, campus organizations), was limited currently due to the GAL size and corresponding attendance cap. However, these differences also reinforce the adaptability of our peers in running outreach events based on institutional needs and available resources.

One area of interest for our group was determining the appropriate attendee: facilitator ratio for similar events and how that impacted the numbers of students per group. Most reports did not provide enough detail for us to determine an appropriate ratio; however, Redway et al. (2023) provided the closest amount of information. During their large-scale outreach event, they had multiple facilitators, selected from their Anatomy Outreach Team (AOT). The AOTs consisted of over 100 dedicated health professional students (*e.g.*, medical, dental), undergraduate students, and anatomy graduate students. In reconstructing this information based on ~16 students per station and one to two facilitators per station, we estimated an attendee: facilitator ratio ranging from 16:1 to 8:1. The higher ratio is the same as our 2023 event, and the lower ratio matches our preferred staffing based in the 2024 and 2025 events. More commonly, reports like Mathis et al. (2020) indicated the number of attendees per group that rotated through GAL activities as opposed to a specific ratio. We hope that future descriptions of GAL in-reach and outreach events provide details regarding numbers of facilitators and attendees to allow faculty to adapt models at their home institutions.

Like outreach events (*e.g.*, Mason et al., 2024; Redway et al., 2023), we also used graduate students as facilitators. This not only allowed us to maintain an optimal student: facilitator ratio but provided the graduate students with valuable teaching experience for a future career (Meyer et al., 2018). There is an increasing demand for highly trained anatomy instructors in a continually expanding health education market; however, the demand is outpacing the supply (Garnett et al., 2023). Departmental chairs reported that they anticipated the greatest difficulty for future faculty recruitments would be to teach gross anatomy (Wilson et al., 2020). In the same survey, chairs identified that versatility in teaching methods was desirable for future applicants. Therefore, the utilization of graduate trainees in GAL-focused activities has dual benefits: attendees gain exposure to the healthcare fields and facilitators gain teaching opportunities related to career development and advancement.

Advertisement and communication methods were also similar between our in-reach events and reported outreach events. Ruth et al. (2023) and Redway et al. (2023) emphasized the need to coordinate recruitment and messaging with teachers for bringing high school students into the lab. Given the scale, these events also included administrative support for navigating scheduling. Conversely, Mathis et al. (2020) discussed the recruitment process through the coordination of a faculty event organizer and student group, like our own event. All studies detailed the additional need for preparatory communication for visiting a GAL, including event logistics, appropriate attire, and preparing for varied emotional responses. Therefore, we have grounded our in-reach event with best practices used in outreach events.

Another major consideration for our in-reach event and other outreach events was the logistics of the event, including overall content and the timing of stations and their respective content. Previous work utilized 10-minute stations and found that both students and facilitators preferred more time at each station (*e.g.*, Mathis et al., 2020; Redway et al., 2023; Ruth et al., 2023). We utilized 15-minute stations, which seemed to be the right amount of time for most respondents. Although several reports identified stations or activities outside of a GAL and donors, including graduate student panels, radiographic imaging, Anatomage® tables, and games (Mason et al., 2024; Mathis et al., 2021; Redway et al., 2023), we did not include these formats in our event due to logistical issues. However, for institutions without a GAL, these formats could be substituted, with stations including models or games as opposed to whole-body donors and prosections. For events with a GAL format, our stations mirrored the existing literature in focusing on basic regional anatomy, clinical correlations and taught with prosections. While we had dedicated prosections for the event as did Redway et al. (2023), Ruth et al. (2023) did not, opting to use those donors being dissected in concurrent programs. Therefore, for either in-reach or outreach events, there is flexibility in what teaching materials to include depending upon institutional access and regulations.

The final step was to evaluate our in-reach event, which has led to several improvements. This was a major gap identified in 2024. As Knippenberg et al. (2020) recognized, this step is critical to improve and strengthen future program iterations. Although our respondents reported high satisfaction with the GAL event (98.8%), consistent with the satisfaction and enjoyment ratings of previous studies (Mathis et al., 2020; Redway et al., 2023), we did have one specific gap. Most outreach events included a central nervous system station (*e.g.*, Mathis et al., 2021; Redway et al., 2023), which we did not have in 2023 or 2024. Based on feedback, we added this new station in 2025 and it was received positively by respondents.

Although most respondents were satisfied with the introductory and closing remarks, including addressing emotional impact, three respondents (3.7%) were neutral or unsatisfied. One respondent specifically indicated feeling unprepared for viewing the donors. Although this is a small proportion of the total respondents, these data suggest that some attendees may have struggled with engaging with the donors. We were unable to find this phenomenon in existing outreach descriptions. However complex emotions,

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both positive and negative, surrounding death and dying exist whether using dissection or prosection in GAL formats (Lai et al., 2023). Working with donors offers what Evans et al. (2018) refer to as "Nontraditional Discipline-Independent Skills," or skills related to professionalism, empathy, love, resilience, and emotional intelligence, among others. Others have argued that the GAL offers a psychologically safe environment for confronting complex emotions and developing these skills before facing them in higher-stakes clinical care settings (*e.g.*, McConnell et al., 2018). Given these benefits, we will continue to monitor and adapt the introduction to the GAL, as necessary.

Our second goal was to compare the results of the event for reinforcing healthcare career interest among pre-health professions students with the existing literature on outreach events for promoting healthcare careers more broadly. This goal was a further extension of the event evaluation, as it provided us with more detailed information on tailoring the event to our pre-health professions student population. We acknowledge limitations in direct comparisons between reported events and our data due to differences in study design. We designed our surveys for internal quality control purposes only, and, as such, our survey data is not as robust as other survey data reported in the literature. Our response rates were low and consistent with trends in medical education research (Reed et al., 2007); however, we recognize that it limits our ability to make gross extrapolations of the data.

With those limitations acknowledged, respondents gave high marks when answering questions related to the relevance of the experience to future careers. One respondent emphasized that the event was "important for students to experience before deciding if the pre-health path is right for them." In addition to relevance, respondents also reported a high likelihood of recommending a future event to friends and peers, supporting existing literature on the positive impact that these types of events have on student attendees (Mathis et al., 2020; Meyer et al., 2018; Redway et al., 2023; Ruth et al., 2023). These data demonstrate that GAL events, regardless of in-reach versus outreach format, are consistently opportunities that attendees think others should experience. We hope that these findings may serve as an encouragement to others who would like to start hosting either an in-reach or outreach event but have yet to do so.

Most respondents were also pursuing a pre-health track, indicating that the event may be important for this population of students. Our results also support previous work failing to find significant changes in interest in pursuing medicine, health, or science careers after attending an outreach event (Mathis et al., 2020; Redway et al., 2023; Ruth et al., 2023). Given the low response rate, it is possible that we are observing a selection bias from those who viewed the event positively. Additionally, we may not be able to observe an increase in attendee interest in pursuing medicine because they were all members of a pre-health student organization.

Our difficulty in making direct comparisons with outreach models is also exemplified by limited detail concerning attendee demographics. Due to the goals of outreach events in promoting visibility for healthcare careers, information like gender, educational background, and prior academic coursework is commonly included in outreach surveys. (Mathis et al., 2020; Redway et al., 2023; Ruth et al., 2023). Because we did not anticipate needing this information when we developed the first survey in 2024, we did not include it. However, with additions to our 2025 survey, we now have a better understanding of their intended majors, the majority of which are in biology, public health, and neuroscience.

We also have a clearer understanding of whether or not attendees are interested in biomedical graduate degrees, with 50% indicating a potential interest in pursuing one. The literature has primarily focused on completing professional degrees, which include graduate degrees, but may not be classified as biomedical. For example, the study by Mathis et al. (2020) demonstrated that 84% of respondents indicated an intention to apply to graduate school but did not specify degree programs. Redway et al. (2023) reported that 50% of high school respondents wanted to attend a professional program, with medical programs being the most popular. Sens et al. (2017) addressed this concept in their study on undergraduate research at rural, primarily undergraduate institutions. Of those students who participated in their research program, 15.3% pursued PhDs. Degrees in health professions were broadly grouped together and represented the next highest percentage at 13.1%. Therefore, our work supports larger trends related to the intentions of outreach event attendees to pursue graduate degrees in biomedical and health professions.

An unexpected opportunity that we identified from the in-reach event was a better perspective on our Human Anatomy Minor and related courses. Survey data indicated that most attendees (96.3%) were not currently enrolled in our Human Anatomy Minor. Following the events, 42.0% of respondents indicated that they were likely or extremely likely to enroll. While we initially considered that this was due to lack of awareness of the minor, survey data from 2025 demonstrated that most respondents (70.6%) were aware of it. Free response data highlighted two comments regarding challenges in enrolling in the minor, specifically those related to scheduling and logistics. Anecdotally, facilitators also reported similar discussions with students during the event. Freshman and sophomore students had expressed interest in enrolling in the courses but could not because the courses were reserved for juniors and seniors. Other students expressed an inability to take Human Anatomy Minor classes during their junior and senior years due to scheduling issues with their major coursework. As we move forward with the in-reach event, we are also examining the current structure of the Human Anatomy Minor, our courses, and barriers for potential students.

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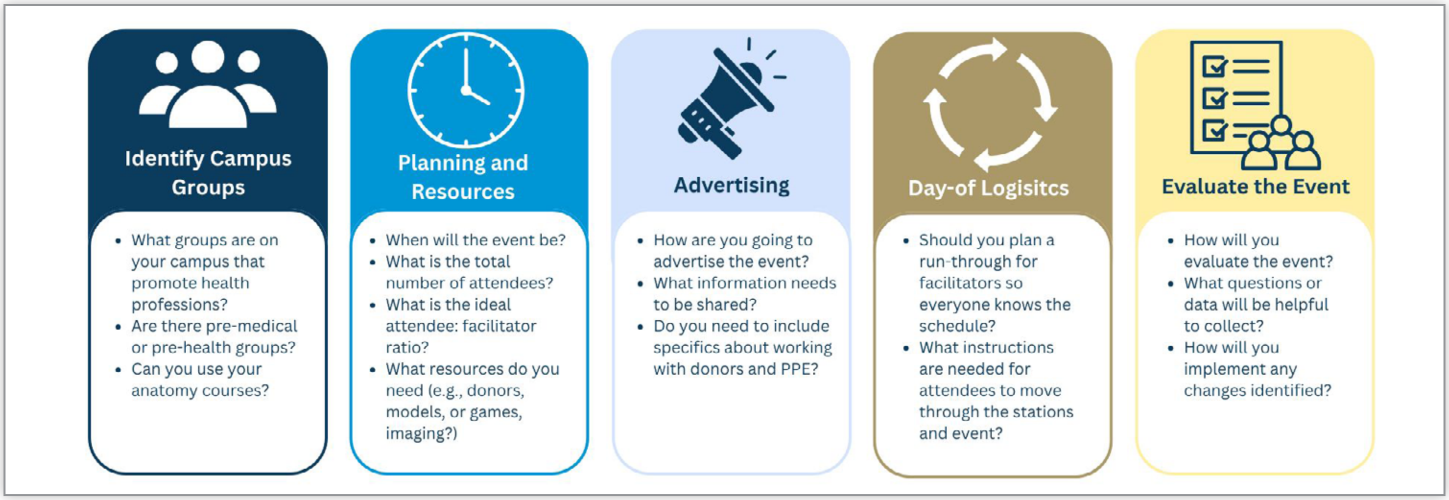

Figure 2. *Suggestions for planning an in-reach event. Questions are included to guide planning process through each recommended step.*

Based on our experiences over the past few years planning an in-reach event, we provide the following suggestions and guided questions for those interested in pursuing such events (Figure 2). First and foremost, interested faculty should work with groups on campus that promote the health professions or pre-health majors. These may include a group like the AMPC, or students in anatomical science courses. Second, allocation of significant planning time for the event is needed. This planning time allows for identification of resources needed (donors, models, etc.) and sorting out event timing. Our prior experience in running large-scale prosection-based events with our medical curriculum eased our planning process; however, faculty should consider what additional planning time if needed if this is not the case. If the GAL and donors are available, then inclusion of stations that represent a wide range of anatomical structures and clinical correlations would be beneficial. You should also determine an appropriate student: facilitator ratio for staffing purposes. If faculty shortages are a concern, then it may be necessary to consider graduate students or other student volunteers. Third, is your advertising plan, what information needs to be communicated, and who will handle the communication. For GAL events, attendees should have an introduction to encountering donors, including potential emotional reactions. Fourth, there are the logistics for the day-of event, including a walk-through for facilitators and clear communication for all attendees in how to flow through the stations. Finally, include an event evaluation to continually monitor and implement changes year after year.

Limitations

We acknowledge several limitations with our in-reach event and its subsequent analysis that we have reported here. First, we have limited information on the students in the AMPC besides the number currently enrolled. Second, the survey was not initially intended to be part of a research study and therefore there were missed opportunities to collect more detailed demographic information. Third, the number of respondents to both the 2024 and 2025 surveys is low and thus does not allow as robust an analysis of the results as we had hoped. Fourth, demographic information regarding the AMPC membership is lacking, potentially further skewing the results of the analysis. And finally, the event was limited due to logistical issues surrounding faculty availability, laboratory space and availability, and resource availability (*e.g.*, whole-body donors). Although some of these were out of our control and/or immutable (*e.g.*, laboratory space) others, such as survey construction, can be altered to provide a more robust analysis of the results and will be noted and adjusted in future events.

Conclusion

Based on our experience and improvements from 2023 to 2025, we view our GWUGAL In-Reach Event as a positive exercise for attendees and facilitators, highlighting the continued sustainability for the now-annual event. We have provided steps for those who want to use the information to plan an in-reach event in the future. Additionally, this type of event allows self-identified pre-health students to get a valuable experience for reinforcement of their career path desires. We will continue to offer this annual GAL in-reach event with the cooperation of the GWU AMPC to promote interest in healthcare careers.

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Appendix 1. 2025 GAL In-Reach Event Schedule

Topic	**Timeslot**
Facilitator Debrief	8:30-9:00am
Group 1	
PPE and Introduction	9:00-9:15
Station 1	9:15-9:30
Station 2	9:30-9:45
Station 3	9:45-10:00
Station 4	10:00-10:15
Station 5	10:15-10:30
Closing Remarks and Facilitator Break	10:30-11:00
Group 2	
PPE and Introduction	11:00-11:15
Station 1	11:15-11:30
Station 2	11:30-11:45
Station 3	11:45am-12:00pm
Station 4	12:00-12:15
Station 5	12:15-12:30
Closing Remarks and Facilitator Break (with Lunch)	12:30-1:30
Group 3	
PPE and Introduction	1:30-1:45
Station 1	1:45-2:00
Station 2	2:00-2:15
Station 3	2:15-2:30
Station 4	2:30-2:45
Station 5	2:45-3:00
Closing Remarks	3:00-3:10
Clean-Up	3:10-4:00pm

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Appendix 2. Attendee responses to quality improvement surveys for the GAL in-reach event.

	Demographic	2024 Survey N (%)	2025 Survey N (%)
Academic Level	Freshman Sophomore Junior Senior	14 (27.7) 16 (34) 14 (29.8) 4 (8.5)	19 (55.9) 8 (23.5) 3 (8.8) 4 (11.8)
Current or intended major	Biology Public Health Neuroscience Psychology Exercise Science	N/A	11 (32.4) 10 (29.4) 8 (23.5) 3 (8.8) 2 (5.9)
*Pursuing a Pre-Health Track	Yes No	41 (89.1) 5 (10.9)	32 (94.1) 2 (5.9)
Interested in pursuing a biomedical graduate degree (e.g., Master's, PhD)?	Yes No	N/A	17 (50.0) 17 (50.0)
Relevance of Laboratory Experience to Future Career	Not Important Slightly Important Neutral Important Very Important	0 (0.0) 0 (0.0) 0 (0.0) 6 (12.8) 41 (87.2)	0 (0.0) 0 (0.0) 1 (2.9) 3 (8.8) 30 (88.3)
Likeliness to Recommend Future Laboratory Events to Friends/Peers	Extremely Unlikely Unlikely Neutral Likely Extremely Likely	0 (0.0) 0 (0.0) 0 (0.0) 3 (6.4) 44 (93.6)	0 (0.0) 0 (0.0) 0 (0.0) 1 (2.9) 33 (97.1)
Satisfaction with Laboratory Experience	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 1 (2.1) 4 (8.5) 42 (89.4)	0 (0.0) 0 (0.0) 0 (0.0) 2 (5.9) 32 (94.1)
Aware of the Human Anatomy Minor	Yes No	N/A	14 (70.6) 10 (29.4)
Enrolled in Human Anatomy Minor	Yes No	2 (4.3) 45 (95.7)	1 (2.9) 33 (97.1)
*Likeliness to Enroll in Minor After Attending Event	Extremely Unlikely Unlikely Neutral Likely Extremely Likely	7 (15.6) 8 (7.8) 14 (31.1) 12 (26.7) 4 (8.9)	3 (8.8) 1 (2.9) 12 (35.3) 10 (29.5) 8 (23.5)

	Demographic	2024 Survey N (%)	2025 Survey N (%)
Satisfaction with Event Logistics			
Introduction to the lab and the donors	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 1 (2.1) 1 (2.1) 6 (12.8) 39 (83.0)	0 (0.0) 0 (0.0) 1 (2.9) 5 (14.7) 28 (82.4)
Flow from one station to the next	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 2 (4.3) 7 (14.9) 38 (80.8)	0 (0.0) 0 (0.0) 1 (2.9) 10 (29.5) 23 (67.6)
Time at each station (15 minutes)	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 1 (2.1) 4 (6.4) 14 (31.1) 28 (59.6)	0 (0.0) 2 (5.9) 3 (8.8) 11 (32.4) 18 (52.9)
Abdomen station content	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 2 (4.3) 6 (12.8) 39 (83.0)	0 (0.0) 0 (0.0) 0 (0.0) 8 (23.5) 26 (76.5)
Thorax station content	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 1 (2.1) 6 (12.8) 40 (85.1)	0 (0.0) 0 (0.0) 0 (0.0) 8 (23.5) 26 (76.5)
Upper limb station content	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 1 (2.1) 6 (12.8) 40 (85.1)	0 (0.0) 0 (0.0) 1 (2.9) 8 (23.5) 25 (73.6)
Lower limb station content	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 0 (0.0) 1 (2.1) 7 (14.9) 39 (83.0)	0 (0.0) 0 (0.0) 1 (2.9) 9 (26.5) 24 (70.6)
Central nervous system	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	N/A	0 (0.0) 0 (0.0) 0 (0.0) 8 (23.5) 26 (76.5)
*Closing remarks	Extremely Unsatisfied Unsatisfied Neutral Satisfied Extremely Satisfied	0 (0.0) 1 (2.2) 0 (0.0) 5 (10.9) 40 (87.0)	0 (0.0) 0 (0.0) 0 (0.0) 7 (20.6) 27 (79.4)

**Item had fewer than 47 total responses for 2024.*

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Appendix 3. Free responses from the post-event quality improvement survey for the GAL in-reach event.

	2024		2025	
Category	**Number**	**Comments**	**Number**	**Comments**
Overall satisfaction				
Great educational opportunity and experience	8	"Amazing 10/10" "Thank you so much for holding this event! Such an incredible experience." "I loved it so much it was an amazing opportunity." "Awesome event and I'm looking forward to going again next year!" "I appreciate the opportunity to have come along and become a part of it, I found it very educational." "We are so lucky to have been given the opportunity! Thank you guys!!" "Thank you for hosting this cadaver lab! It was such a cool experience and I will be returning!" "Thank you for this opportunity. It is honestly one of the coolest things I've participated in at GW."	8	"NA. Totally awesome and thrilling!" "The event was really great and I learned a lot!!" "Thank you for this incredible experience!" "Thank you for a great experience!" "Everything was great" "Thank you so much for the opportunity and your efforts " "Loved it!" "Thank you so much!"
Satisfaction with logistics	6	"I think that Dr. Spencer as his team were amazing. They made sure everyone was in a comfortable learning environment and made sure that if there were areas that may be seen as uncomfortable, it was normal to feel any way that you do and at any given point it was ok to step out, leave, or talk to any one of them." "The set up was perfect and had just enough time at each station to learn the anatomy." "No, it was very good" "None! it was a great event and I really enjoyed it! "The set up was perfect and had just enough time at each station to learn the anatomy "It was great! I liked having the four different stations, and I thought that I definitely had enough time with the 15 minutes to experience everything each one had to offer."	2	"It was a really nice setup and such a great experience!" "I enjoyed this year better than last year. Instructors gave more overview and explanation. There was a good balance between getting to explore and instructors teaching. Last year I felt that there was too little instruction and too much time on our own. Loved the instructors asking questions to us"
Importance to healthcare career	1	"Amazing event!! So important for students to experience before deciding if the pre-health path is right for them."	1	"This was such an amazing experience and I think everyone did a great job of explaining everything at each station and giving us time to interact! I learned so much and the experience definitely solidified that I want to go into medicine."
Areas for improvement				
Timing	2	"I just wish it was longer!" "Maybe a little less time at each station"	2	"I kept wishing the sessions for each region of the body were longer!" "I wish each station was a little longer"
Future Changes to Event	3	"I wish there were brains" "While going through the stations I thought the upper and lower limb sections were connected, it was hard to see their "boarders"." "I would love if you could include pins to identify muscles/organs/parts."	0	
Greater clarity on emotional impact and donor variation	1	"The only thing I would change is the introduction to the lab. They initially said the faces would be covered, and they technically were covered but it was a towel that you could see everything through which was a big shock to me when they uncovered them. I would also mention that all the donors are different colors including red and grey and everything in between. I really appreciated having chairs at all the stations as well as the doctors and proctors being incredibly understanding of everyone's feelings."	0	
Comments related to Human Anatomy Minor				
Inability to pursue Human Anatomy Minor	2	"I would do the minor, but I don't have room in my schedule." "The only reason I wouldn't consider a minor is bc I'm a SEAS (School of Engineering and Applied Science) major and I already have a minor, so I could not fit it and graduate on time. However, I would recommend it and if I were a humanities major I would def do it"	0	
New interest in Human Anatomy Minor	1	"This was such a great opportunity, and although I was thinking about pursuing the anatomy minor before, I feel even more inclined to do it now. Thanks for organizing this!"	0	
Total comments	**24**		**13**	

Back to TOC

PERSPECTIVES ON TEACHING

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The Role of Learning Assistants in Supporting Student Success in Large-Enrollment Biology Courses

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Abstract

In large-enrollment science, technology, engineering, and mathematics (STEM) courses such as biology students often struggle with course engagement, receiving individualized support, and feelings of belonging. To address these challenges, peer learning assistants (LAs) have been utilized in these courses to support student engagement with course topics and to promote an inclusive environment. In large courses, students often feel unheard or overlooked leading to feelings of not belonging or not being part of the course. We examined the role of peer LAs in supporting student success and fostering an inclusive environment in a large-enrollment biology course. To assess student perceptions of the benefits of LA support, students were asked to complete a survey at the end of the semester relating to the use of peer learning assistants in the biology course. This study was novel in the respect that the use of LAs was embedded within the lecture sessions, during activities, and also in resources outside of class (review sessions, group learning sessions). Results indicated that the use of LAs in the biology class provided the support students required to succeed in the course. When class activities were included as part of the course curriculum, students were found to be more engaged during active learning and to then seek help from the LAs outside of class. Students reported that they participated in class activities, they found the active learning to be helpful in mastering course concepts, and they utilized the LA resources, enhancing their overall success in the course.
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Key words: inclusivity, learning assistants, student success, engagement, STEM education

Introduction

Large-enrollment biology courses present unique challenges for both educators and students. The large number of students in these courses often leads to limited opportunities for individualized instruction, active participation, and meaningful engagement with course material (Freeman et al., 2014). Additionally, the diversity of students in such courses necessitates inclusive pedagogical practices to ensure equitable learning opportunities and support for all students, particularly those from underrepresented backgrounds in STEM fields (Haak et al., 2011; Hernandez et al., 2021).

In this context, the Learning Assistant (LA) model has emerged as a promising approach for improving student success while also humanizing the classroom experience. LAs are undergraduate students who, after receiving targeted training, collaborate with faculty to facilitate active learning and peer-to-peer interactions (Otero et al., 2010). Typically, they have previously completed the course, and they support current students through in-class facilitation, regular preparation meetings with instructors, and pedagogical training focused on how students learn (Clements et al., 2022). A recent scoping review concluded that the LA model is consistently associated with improved student outcomes and with more student-centered instruction across STEM, even as the field continues to call for more rigorous and context-specific research (Barrasso & Spilios, 2021). At the institutional level, LA adoption has also been linked to stronger retention and graduation outcomes, with especially promising associations for Black and Hispanic students, suggesting that the model may contribute not only to course-level success but also to broader equity goals in STEM pathways (Feng et al., 2025).

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Student Benefits

For large-enrollment biology courses, in particular, the value of LAs appears to extend beyond academic performance alone. In introductory biology, incorporating LAs has been shown to increase students' sense of belonging and engagement across both in-person and online course structures, with students describing LAs as approachable, immediate sources of help who reduced feelings of isolation and made participation feel more attainable (Clements et al., 2022). Similarly, in a large-enrollment molecular biology course, adding LAs to an already active, highly structured format improved performance on higher-order assessments and was especially beneficial for students from groups underrepresented in STEM, indicating that LAs can strengthen the benefits of active learning (Sellami et al., 2017). Emerging work across science disciplines has further suggested that LAs foster belonging and confidence by creating supportive classroom climates, facilitating responsive pedagogy, and helping students connect to STEM pathways and campus networks (Clements et al., 2025). Recent work in general microbiology also points to the practical value of structured undergraduate LA programs for sustaining engagement in high-enrollment courses while providing a replicable framework for mentorship and instructional support (Popichak et al., 2025). Taken together, these findings suggest that LAs are more than an instructional supplement; they are a relational and pedagogical resource that can promote student success, deepen engagement, and foster more inclusive learning environments in large-enrollment biology and other STEM courses (Dewsbury & Brame, 2019; Clements et al., 2022).

The Role of Learning Assistants

LAs are typically selected based on their academic performance, communication skills, and interest in teaching (Otero et al., 2010). They undergo training to develop pedagogical skills and are integrated into the course to support both students and instructors. The specific roles of LAs include:

Facilitating Active Learning: LAs assist in implementing active learning strategies such as group discussions, problem-solving sessions, and hands-on activities (Otero et al., 2010).

Providing Individualized Support: LAs offer one-on-one or small group tutoring, helping students with varying levels of understanding (Estrada et al., 2011).

Bridging Communication Gaps: LAs serve as liaisons between students and instructors, providing feedback and addressing student concerns (Knight et al., 2013).

Enhancing Engagement: By interacting with students during classes, LAs encourage participation and create a more interactive learning environment (Goertzen et al., 2011).

Reducing Anxiety and Increasing Confidence: The presence of LAs can reduce student anxiety, as peers may find it easier to ask questions and seek help from LAs than from instructors (Talbot et al., 2015).

Learning Assistants and Active Learning

Active learning strategies have been widely recognized as effective in improving student outcomes in STEM education (Freeman et al., 2014). By engaging students in activities that require analysis, synthesis, and evaluation of course material, active learning fosters a deeper understanding and retention of knowledge. However, implementing active learning in large classrooms can be logistically challenging due to the high student-to-instructor ratio (Cooper et al., 2018). LAs may address this issue by serving as intermediaries who facilitate small-group discussions, provide guidance during in-class activities, and offer personalized support. The LAs provide student support for activities that focus on difficult concepts, and they foster interactions which support student learning. Courses utilizing LAs have demonstrated increased student engagement and improved academic performance compared to traditional lecture-based courses (Goertzen et al., 2011).

Inclusivity in STEM Education

Inclusivity in STEM education is critical to broadening participation and reducing achievement gaps among students from different demographic and socio-economic backgrounds. Large-enrollment courses often exacerbate feelings of anonymity and marginalization among underrepresented students, leading to lower retention rates (Haak et al., 2011). The presence of LAs in the classroom has been linked to a more inclusive learning environment, as LAs often serve as relatable role models and provide a supportive peer network (Talbot et al., 2015). Students perceive LAs as approachable and empathetic, which can encourage participation from students who might otherwise feel hesitant to engage in a large class setting (Knight et al., 2013).

Supporting Student Success

Student success in large-enrollment courses extends beyond academic performance to include persistence, self-efficacy, and a sense of belonging (Estrada et al., 2011). LAs play a crucial role in fostering these outcomes by building positive relationships with students and providing feedback that reinforces their learning. Evidence suggests LA-facilitated courses lead to higher rates of course completion and lower drop/fail/withdraw (DFW) rates (Van Dusen & Nissen, 2020). Furthermore, the training that LAs receive equips them with pedagogical skills that enhance their ability to support diverse learning needs, contributing to an overall positive impact on student success metrics (Otero et al., 2010). LAs specifically work with students during class activities and provide guidance and real-time information to the instructor that supports these class activities.

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The support provided by LAs translates into measurable improvements in student success. Key benefits include:

Improved Academic Performance: Studies have shown that students in courses with LAs tended to achieve higher grades and have better understanding of the material (Goertzen et al., 2011).

Higher Retention Rates: Courses with LAs see higher retention rates (e.g., students who continue their studies following their first year), as students feel more supported and engaged (Van Dusen & Nissen, 2020). This is important as STEM majors are susceptible to changing their major after the first year if they do not perform well in "gateway" courses such as biology.

Positive Student Feedback: Surveys and feedback have consistently indicated high levels of student satisfaction with the support provided by LAs (Otero et al., 2010).

Course Population

The biology course evaluated in this study is usually taken by students in their first and second semesters at the university. The students in the course are drawn from a wide range of majors. While this course is required for science majors such as biomedical sciences, biology, health and exercise science, biomedical engineering, etc., it also satisfies a core university science requirement. Given the diversity of backgrounds, many students (both science and non-science majors) within this course struggle with the course material. Therefore, the use of peer learning assistants was implemented to enhance student engagement and success. The course is taught in the fall and spring semesters with enrollments of 174-300 students. The students in the course sections that were surveyed included the following student demographics: Fall 2023 (two sections) and Spring 2024 (1 section). The total number of students in all three classes was 676 while the total number of students in all sections who answered the survey questions was 238. All courses were taught by the same instructor, with consistent material across all sections included in the survey.

Study Purpose

The purpose of this study was to examine the perceived benefits of using peer educators in a large-enrollment biology course at a large land-grant university.

There are no prerequisites for our large-enrollment, freshman biology course with the result that the content spans a wide range of biology topics that can be difficult for many students. This leads to a course that is content-heavy and usually has a high DFW rate. The use of LAs for the many sections of this biology course was implemented by the university to decrease this high rate of withdrawing from the course or receiving a grade of D or F.

While other studies have shown the benefits of undergraduate LAs, little attention has been given to student-LA activities during in-class activities, student use of LA resources provided outside of class sessions, and whether class activities supported student success and promoted student understanding of course concepts. We examined the effect of in-class activities, implemented during every class session, which promoted student-LA interactions, and the additional resources provided outside of lecture (e.g., LA tutoring, group learning sessions, LA-led exam review sessions), as reported by students, on enhancing student engagement and facilitating student participation with course material.

The use of LAs in large-enrollment biology courses may represent a scalable and impactful approach to addressing challenges related to student engagement, inclusivity, and success. By facilitating active learning, promoting equitable participation, and providing personalized support, LAs may contribute to an improved educational experience for students. As higher education continues to prioritize inclusive and evidence-based teaching practices, the integration of LAs into STEM courses holds promise for improving outcomes and fostering a more diverse scientific community. This study was guided by the following research questions:

1. How often did students attend lectures, interact with the LAs, and participate during class activities?
2. Did students find the class activities helpful in mastering course concepts?
3. Which course resources, involving LAs, did students utilize during the semester?

Methods

IRB Approval

This project was approved by the Institutional Review Board of Colorado State University (IRB #5951), and informed consent was obtained from all participants.

Learning Assistants

At our university, learning assistants are recruited by the learning assistant coordinators, following an application and interview process. The LA coordinators are integral staff working with the instructors and LAs. The coordinators interact with the LAs to train them in pedagogy, meet with instructors to observe LA performance, and contribute to improvements in the LA role within the courses they serve. LAs are former students who have completed the course with a grade of A or B and they are assigned to work with a specific instructor and course section each semester. The LAs attend all class sessions, and a weekly prep meeting with the instructor, for their section. LAs are required to take a 1-credit pedagogy course, taught by the LA coordinators, during their first semester as LAs.

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LA Responsibilities

The goal of using LAs in a large enrollment course was to enhance student engagement through active learning, and to promote inclusivity by providing resources to the students aimed at supporting their success. The LAs provided guidance to the students, by helping them to work through in-class activities. The LAs also connected with the students outside of lecture to provide additional learning opportunities. These included resources such as exam review sessions, group learning sessions, and tutoring.

The following information relates to the learning assistant guidelines, requirements, and resources provided to the students.

- LAs attended all lectures and helped to facilitate active learning. Active learning was administered during every class session. Within each class period the lecture was interspersed with multiple activities, and all activities were facilitated by LAs.
- LAs provided review sessions prior to each exam - discussing the course concepts, providing games, and creating worksheets aimed at highlighting core concepts.
- LAs provided tutoring and group learning sessions at set times throughout the semester.

Class activities specifically utilized LAs as facilitators of learning. The LAs guided students in the completion of the activities and supported the students through development of their critical thinking skills. Activities were varied and different activities were utilized during class sessions depending on the lecture material. Examples of activities implemented in the biology course are shown in Table 1.

Examples of in-class activities included interactive games such as Jeoparty (a version of the traditional Jeopardy game). For this activity, the method implemented was to ask students to answer questions, with each student allowed to answer only one question. The goal was to encourage participation and promote responses from students who usually do not ask/answer questions. As the LAs chose the students, each LA choosing from their section within the class, they were able to ensure different students answered the questions throughout the game. This method worked well, as the LAs encouraged students to try answering the questions. Additionally, LAs explained the answers after each question was answered. This fostered an atmosphere of LA-student interaction and provided a review of material in a positive learning environment.

Concept map activities were used in the course to guide students as they thought about processes and connections relating to specific key concepts. An example of this type of activity would be the process, and steps, of cellular respiration. For this activity, the LAs participated in guiding the students to think through the overall process of cellular respiration, supporting student development of critical thinking skills. This key for this activity is illustrated in Figure 1.

Group discussions of key concepts
Crosswords puzzles (e.g., DNA, cellular respiration, photosynthesis)
Concept maps (e.g., cellular respiration, mitosis, meiosis, gene expression, evolution)
Concept questions for difficult concepts (e.g., DNA replication, transcription, translation)
Critical thinking, complex multi-layered questions, work-through in class
Worksheets
Drawing of processes (e.g., mitosis, meiosis, DNA replication)
Practice/review questions (e.g., worksheets, iClicker questions)
Exam review class participation games (e.g., Jeoparty)
Diagram mapping
Flow charts
Definitions/vocabulary explanations
Punnett squares
Think-pair-share

Table 1. *Examples of engagement promoting class activities that involved LAs.*

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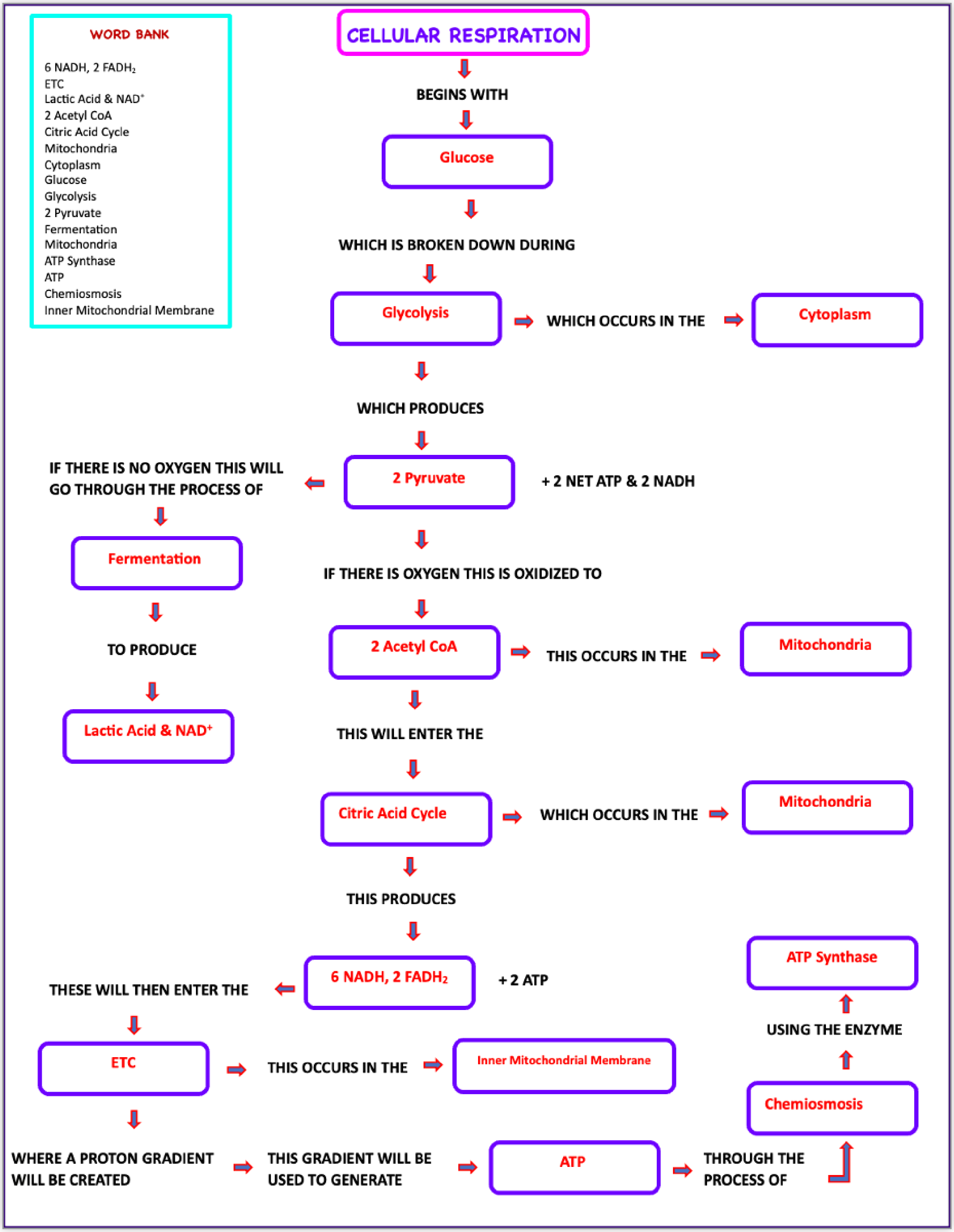

Figure 1. *Example of a concept map activity. LAs guided students to develop their critical thinking skills by working through the process of cellular respiration utilizing a concept map activity.*

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Learning Assistant Student Support

The learning assistants provided support for students both in class (activities), and outside of class (tutoring and group learning sessions, exam review sessions). The group learning sessions were provided during the week, Monday-Thursday, from 5:00-8:00 PM. LAs were available during their scheduled times to answer questions, discuss difficult concepts, explain processes, etc. Exam review sessions were provided once for each exam (total five per semester). These included a Kahoot game with review questions and activities aimed at helping students understand main exam topics (e.g., mitosis, meiosis, transcription, translation, etc.). The exam review session materials were posted on the course web site to ensure access for all students. The tutoring sessions were run by the LAs and students signed up for days/times that fit their schedules (either individually or in groups). All LA resources were available to all students in the course. The class activities were posted as PowerPoint slides or handed out in class. Time was provided for students to work on the activities and to interact with the LAs during the work sessions. This allowed students opportunities to interact with the LAs in real-time as they worked through the course material. All LA resources were optional.

Participants

The participants in this biology course were, for the most part, freshmen, as this course is a prerequisite for many program majors such as biology, biomedical sciences, and biomedical engineering. The course also satisfies the University Core Curriculum science requirement for other majors, resulting in diverse student populations (both science majors and non-science majors). During the semester, the students interacted with the activities and LAs during every class session, in addition to the opportunities provided for assistance outside of class.

Survey Responses

At the end of the semester, students were provided with a survey on their learning management system and asked questions relating to class attendance, participation in class activities, utilization of LA resources during class and outside of class. They were also asked questions relating to their opinions regarding the helpfulness of the in-class activities and the learning assistant resources. Student responses to the survey questions were collected anonymously, and answers were pooled between semesters and presented as percent of students providing a specific response. In the Fall 2023 and Spring 2024 semesters, there were a total of 238 students who completed the survey questions.

The survey was composed of multiple-choice questions and free-response questions. The multiple-choice questions were reported as percentages and depicted in the figures. The free-response answers were used to inform the instructor for future courses utilizing LAs, and some of the responses are reported as quotes. The relevant survey questions, and student response numbers, relating specifically to learning assistant resources and student success, are presented in Table 2.

	Fall 2023 (1)	**Fall 2023 (2)**	**Spring 2024**	**Total**
Did you attend lectures? If yes, how many times per week (on average) did you attend?				
Three times per week	32	31	45	**108**
Two times per week	19	14	50	**83**
One time per week	13	7	18	**38**
Total	**64**	**52**	**113**	**229**
Did you participate in class during the activities (answer questions, complete worksheets, contribute to group discussions, etc.)?				
Yes, I always participated	21	32	39	**92**
Yes, I participated some of the time	39	21	66	**126**
No, I did not participate	4	1	8	**13**
Total	**64**	**54**	**113**	**231**
Did you find the in-class activities helpful for learning/mastering the course concepts/material?				
Yes, I found all of the activities helpful	14	23	32	**69**
Yes, I found most of the activities helpful	38	26	73	**137**
No, I did not find the activities helpful	9	4	7	**20**
Total	**61**	**53**	**112**	**226**
Did you use any of the course resources. If yes, which resources did you use?				
Group learning sessions	9	10	34	**53**
LA tutoring	18	16	33	**67**
LA review sessions	27	28	60	**115**
I did not use any of the course resources	3	6	4	**13**

Table 2. *Student survey responses regarding utilization of resources provided by LAs.*

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Results

Survey respondents reported that they found the class activities helpful and that they utilized the resources provided by the LAs. They responded to survey questions relating to how often they attended lectures, interacted with the LAs, and participated in class activities, whether they found the class activities helpful in mastering course concepts, and which LA-resources they utilized during the semester. The survey results are shown in Table 2. When participants were asked whether they participated in class activities that were led by LAs, most students reported that they participated in the active learning (40% always; 55% mostly; Figure 2).

Students identified whether they found the class activities to be helpful in mastering the course concepts (31% found all activities helpful; 61% found most activities helpful). This is illustrated in Figure 3.

Students utilized a variety of LA resources offered during the semester (22% attended group learning sessions; 28% accessed tutoring; 48% used review sessions; Figure 4). This was especially relevant, as the wide variety of resources provided different types of learning aimed at supporting different learning styles, promoting inclusivity, and ensuring that the needs of many different students were met.

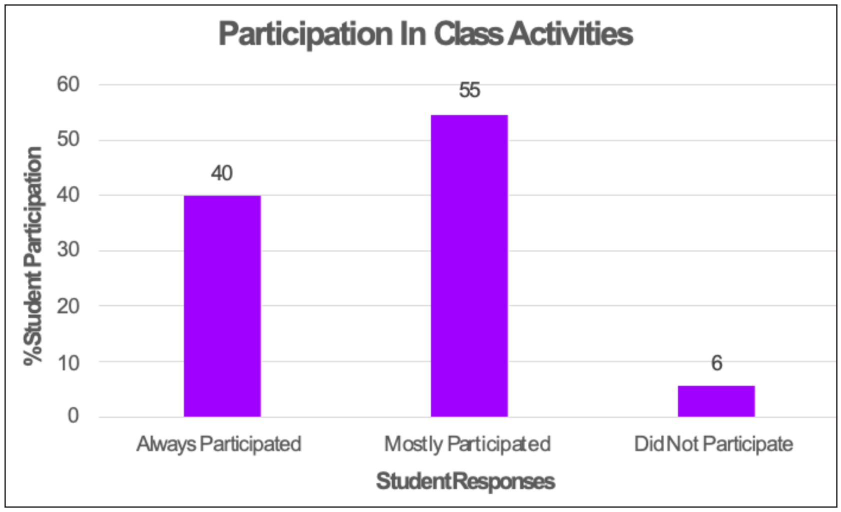

Figure 2. *Students self-reported participation in class activities. When asked via survey if they participated in class activities led by LAs, most students reported that they participated (40% always participated; 55% mostly participated).*

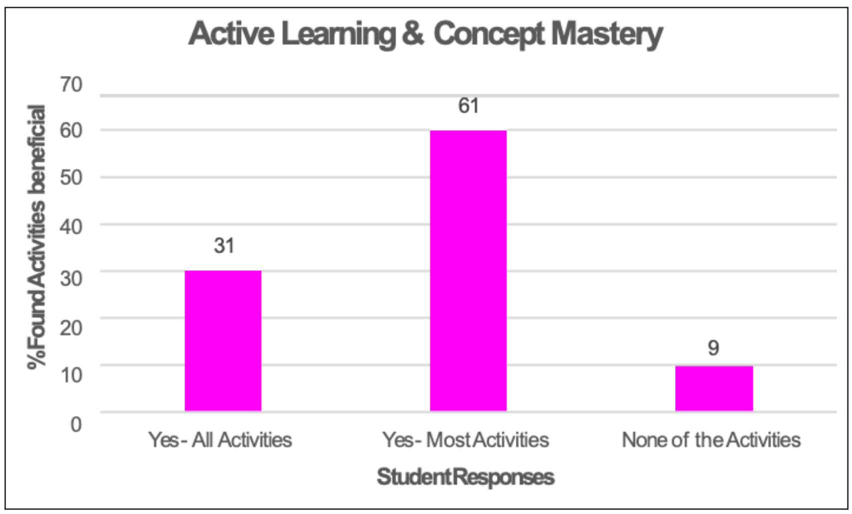

Figure 3. *Students identified if they found the class activities to be helpful in mastering course concepts (31% found all activities helpful; 61% found most activities helpful).*

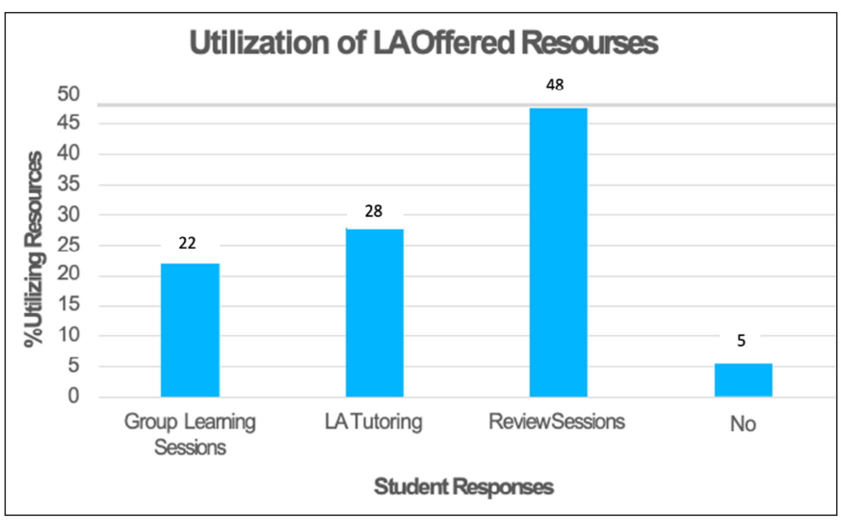

Figure 4. *Students reported via survey that they utilized a variety of LA resources offered during the semester (22% used group learning sessions; 28% accessed tutoring; 48% attended review sessions).*

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Many survey respondents reported that they found the LAs and the activities helpful in learning the course content. The representative quotes (Table 3) indicate that students found the class activities, the LA review sessions, and the LA group learning sessions/tutoring to be beneficial in supporting their success in the course. As the survey questions asked for which activities were helpful, the quotes are necessarily positive.

The in-class activities were a fun way to engage and helped me connect the concepts after we had discussed them in class.
I believe that the in-class activities were the most helpful. Biology is difficult and content heavy, so having activities to help with understanding of the lecture content was extremely helpful.
I really liked the activities and thought that they were a good way to actively use our new knowledge. I also used them for review.
I found all of the exam review sessions extremely helpful, as well as the worksheets/activities we did during lecture.
I think the activities we did in class and the exam review sessions really contributed to my success in this class.
I found the review sessions to be very useful before the exams. They helped me review main concepts and prepare for the exam.
Regular attendance to lecture sessions, taking notes during said sessions, and engaging with in-lecture activities and worksheets were crucial.
I found the worksheet to be useful and the LA review sessions to be very helpful.
When the LA's walked around to help answer questions that is when most of the information I was struggling on was answered.
I found the LA review session before the exam very useful! I loved being able to get my answers answered in real life and found the worksheets and review games a great way to test my prior knowledge.

Table 3. *Representative student survey responses relating to interactions with LAs during in-class activities and outside of class.*

While many responses were positive as shown in Table 3, there were also negative responses to the use of LAs and LA resources. As these negative responses related to students not attending class, not participating in the class activities, or not utilizing the LA resources, these were not included in the table. More specifically, the responses shown in the table were related to questions aimed at defining whether the students who attended class, participated in activities, and utilized the LA resources found them helpful and supported their success in the course.

Discussion

Classroom Climate

A positive classroom climate is essential for supporting student success, as this ensures that all students feel welcome and heard. The goal of utilizing LAs in our biology course was to promote an encouraging and supportive class environment conducive to increasing student learning and involvement. Many students indicated in their survey responses that the LAs, class activities, and LA resources supported their learning in the course through LA-led support. We believe that the LAs, as they are peer instructors, more closely represented the student culture in the class and their role as peer educators could promote a more involved class environment. LAs are an excellent tool for promoting student motivation and inclusivity within the classroom, for enhancing the classroom climate, and for improving pedagogy and instructional strategies. Utilizing LAs supported the goal of creating a safe and inclusive learning environment in the course.

Students indicated positive benefits from integration and involvement of LAs in the biology course. Students reported that integration of undergraduate LAs in their large-enrollment biology course enhanced student learning, supported student success and encouraged engagement. These findings align with previous studies highlighting the effectiveness of peer-assisted learning strategies in higher education, particularly in STEM disciplines where active engagement can significantly influence outcomes (Freeman et al., 2014).

Student Success

One of the positive outcomes of this implementation was the reported enhancement in student learning of course materials. The use of active learning strategies, facilitated by LAs during class sessions, emerged as a cornerstone of this success. Active learning, characterized by collaborative problem-solving, small-group discussions, and real-time feedback, has been shown to improve understanding and retention of biological concepts (Haak et al., 2011). By embedding LAs into this process, students had access to near-peer mentors who could provide relatable insights, clarify misconceptions, and scaffold learning in a manner

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distinct from that of instructors. This peer dynamic likely reduced the intimidation factor often associated with seeking help from faculty, thereby fostering a more supportive and approachable learning environment. The survey results and the selected student quotes indicate that students found the LA-facilitated class activities and the LA-led review sessions to be beneficial to their overall success in the course.

Inclusivity

Inclusivity was another significant dimension of the LA program. Large enrollment courses often present challenges in ensuring that all students feel seen, heard, and supported. The presence of LAs in class helped mitigate these challenges by creating smaller, more intimate learning communities within the larger class structure. Active engagement of the LAs during class sessions ensured that students from diverse backgrounds had equitable opportunities to participate, ask questions, and contribute to discussions. By reflecting the diversity of the student body, LAs also served as role models, demonstrating that success in biology is achievable for all students, regardless of their background.

Student Engagement

Support for student success extended beyond the classroom through the organization of LA-led exam review sessions. These sessions were particularly praised by participants for their effectiveness, as they provided targeted opportunities for students to review key concepts, address areas of difficulty, and practice application-based questions in a low-pressure environment. The familiarity and accessibility of LAs likely enhanced the perceived value of these sessions, as students felt more comfortable engaging actively without fear of judgment. This resource proved beneficial in preparing students for assessments, as students reported they believed these sessions contributed to their learning success.

Student engagement, both during class and in supplementary sessions, also increased as a result of the LA program. The involvement of LAs helped create an interactive and participatory learning environment, counteracting the passive learning tendencies often observed in large lecture-based courses. Students' appreciation for LA-led activities underscores the importance of peer involvement in fostering a sense of community and accountability within the classroom. The use of LAs in our biology course specifically addressed the needs of students in mastering course concepts by their provision of active learning opportunities. This extensive use of the LAs as facilitators of in-class active learning was unique in a content-heavy biology course. The resources provided by the LAs outside of class (e.g., tutoring, group learning sessions, exam review sessions) supported student learning beyond the classroom, and these additional sources of student support promoted the benefits described by the students in their survey responses.

Moving forward, this use of LAs holds significant promise for adoption and adaptation in other large-enrollment courses across disciplines. To maximize its potential, it is recommended that institutions provide training for LAs, to ensure alignment between LA-delivered activities and instructional goals, and to continuously assess the program's impact through student feedback and performance metrics. By doing so, the benefits of this approach can be sustained and scaled, ultimately contributing to a more inclusive and effective educational landscape.

The involvement of LAs is beneficial for student development especially if a student group does not feel comfortable interacting outside of class with the instructor. Thus, this helps with allowing different socio-cultural student groups to feel included and to receive course help. LAs are an important and useful component of creating an inclusive and connected class. These undergraduate peer instructors help to promote a sense of community in the class, and they are beneficial in supporting student success. The use of LAs supports inclusivity by reaching many different student groups, by guiding students on their learning journeys, and by providing additional learning resources to promote success.

Conclusion

Students reported that the use of undergraduate LAs in a large-enrollment biology course was a positive approach to enhancing their overall learning experiences. The reported benefits: improved understanding of course materials, increased engagement, promotion of inclusivity, and support for student success, highlight the multifaceted impact of integrating peer-assisted learning strategies.

Active learning during class sessions, facilitated by LAs, and LA-led exam review sessions, seemed to be effective components of this approach. These elements supported enhanced comprehension and retention and fostered a supportive and inclusive environment, where students felt empowered to take an active role in their learning journeys. By bridging the gap between students and instructors, LAs played a role in creating a classroom culture that values collaboration, equity, and academic excellence.

Limitations

The survey was designed to ask students multiple-choice and free-response questions directly relating to their class attendance, their class participation in the active learning activities, and their use of the LA resources provided during the semester. However, demographic information (gender, first-generation status, under-represented minority status, etc.) was not included in the survey. In future studies, this information will be included in the survey questions and collected from all students, to enhance the strength of the

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study and survey results. Additionally, the survey responses were voluntary and did not include all students in the course. It would be beneficial in future courses to include the survey as a required component of the class (with an option to have their responses excluded from the analysis) to increase the number of students completing the survey.

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Back to TOC

PERSPECTIVES ON TEACHING

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BuckeyeView: An Interprofessional Model for Developing Integrated Anatomy Education Platforms

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Abstract

Integrated undergraduate medical education (UME) curricula emphasize connections among foundational sciences but often face challenges related to reduced instructional time and fragmentation of supplemental learning resources. Concurrently, medical students increasingly rely on digital platforms to supplement formal instruction, creating opportunities for institutions to develop internally aligned educational tools that support integrated learning. BuckeyeView is an interprofessional educational innovation developed at The Ohio State University College of Medicine to address these challenges. Initiated through a student-driven, faculty-supported partnership, the project brought together medical students, doctoral trainees in anatomical sciences, faculty educators, undergraduate computer science students, and digital visualization specialists. Through iterative collaboration, the team developed an interactive web-based educational platform featuring three-dimensional cadaveric models generated using photogrammetry-based reconstruction techniques. These models serve as integrative anchors linking anatomical structures with related foundational science concepts and clinical applications. The development process yielded several key insights: interprofessional collaboration can accelerate educational innovation by integrating diverse expertise, student-driven development promotes learner-centered design, and, student-led projects require flexible workflows to accommodate academic schedules. BuckeyeView demonstrates how interprofessional collaboration can support the creation of institutionally aligned digital learning resources. This model may inform future efforts to develop integrated educational technologies within evolving medical curricula. https://doi.org/10.21692/haps.2026/019

Key words: interprofessional collaboration, anatomy education, medical education innovation, digital learning platforms, integrated curriculum

Introduction

Undergraduate medical education (UME) continues to evolve in response to the exponential expansion of medical knowledge and rapidly shifting societal, healthcare, and educational landscapes. A defining feature of this evolution has been the transition from traditional discipline-based curricula to integrated models that emphasize horizontal and vertical incorporation of the basic sciences to enhance clinical relevance and highlight interdisciplinary connections (Bolender et al., 2013). While integration offers important advantages, it has also introduced structural and pedagogical challenges for both educators and learners.

Anatomy education has been particularly affected by these shifts. Reduced contact hours, decreased laboratory dissection experiences, and concerns regarding foundational knowledge acquisition and application have prompted ongoing dialogue about how best to preserve educational depth while promoting integration (Bolender et al., 2013; Brooks et al., 2015; Hartley et al., 2018; Lazarus et al., 2014; Pakanen et al., 2022; Serrat et al., 2014). Paradoxically, the mechanisms by which students most effectively acquire anatomical knowledge – memorization, contextualization, and experiential engagement – align closely with the goals of integrated curricula (Wilhelmsson et al., 2010). Contextualization develops as learners move from recognizing intra-anatomic relationships to integrating functional relevance across disciplines, culminating in application of knowledge within professional contexts. Anatomy therefore remains well positioned to serve

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as an anchor discipline within integrated models, provided that instructional design intentionally supports connection building across subdisciplines and clinical applications (Bolender et al., 2013; Wilhelmsson et al., 2010). Previous investigations of anatomy within integrated curricula have identified several themes associated with successful implementation, including student-centered and interactive learning approaches, deliberate balancing of anatomic detail with clinical relevance, early incorporation of radiologic and cross-sectional anatomy, and longitudinal reinforcement of foundational concepts throughout the curriculum (Bhangu et al., 2010; Brooks et al., 2015; Hartley et al., 2018; Serrat et al., 2014).

Concurrently, medical students have increasingly relied on digital learning platforms to supplement formal instruction. Surveys suggest anatomy websites are among the most frequently utilized learning tools (Leung et al., 2020), reflecting a broader generational shift toward digital content engagement, a trend of particular importance for anatomy educators. While digital platforms offer flexibility, repeatability, and opportunities for interactive learning, the proliferation of externally developed resources introduces variability in accuracy, depth, and alignment with institutional curricular goals. Moreover, many supplemental tools focus narrowly on single disciplines, potentially reinforcing educational fragmentation rather than supporting the integrated frameworks now characteristic of UME.

Digital innovation within anatomy education continues to expand, driven by a combination of instructional necessity, learner preference, and technological capability. Educators have found that incorporation of interactive media, gamification strategies, and artificial intelligence-supported tools has been associated with improved retention and application of anatomical knowledge (Castellano et al., 2024; Patra et al., 2022). These findings support educator interest in digital learning modalities as an effective avenue for addressing increasing limitations on in-person instruction. Collectively, this suggests that thoughtfully designed digital resources can complement traditional instructional approaches while simultaneously enhancing learner engagement and success (Patra et al., 2022). However, the question remains how institutions can develop internally aligned digital tools that reflect curricular priorities while maintaining scientific rigor and accessibility.

At The Ohio State University College of Medicine (OSUCOM), anatomy instruction transitioned in 2011 from a stand-alone course integrating gross anatomy and embryology to the current Lead.Serve.Inspire (LSI) curricular format, with foundational anatomy content introduced early within each organ system-based preclinical unit to support subsequent understanding of physiologic and pathologic processes. This transition reduced centralized anatomy contact time and reinforced the need for supplemental resources capable of supporting anatomy learning across integrated curricular blocks. Within integrated curricula such as this, technological learning tools have demonstrated positive student perceptions and measurable educational benefit (Olivares-Perez et al., 2022; Souza e Silva et al., 2024). Recognizing both the opportunities and limitations inherent in integrated and digitally mediated learning environments, we undertook the development of BuckeyeView—an interprofessional, web-based educational hub designed to anchor integrated anatomy learning through interactive three-dimensional cadaveric models and cross-disciplinary linkage.

This article describes the collaborative process underlying BuckeyeView's development, the pedagogical principles guiding its design, and the lessons learned through interprofessional educational website development. We conclude with reflections and future directions relevant to educators seeking to develop institutionally aligned digital resources within integrated curricula.

Project Conception and Educational Rationale

As integrated curricula have evolved, students increasingly navigate a broad ecosystem of supplemental digital resources. Within our own institution, informal student feedback and observation suggested that many learners supplemented—or in some cases replaced—components of the institutional curriculum with multiple independent online platforms. While these resources often provided strengths within specific domains, few offered integrated perspectives across anatomical subdisciplines or clear alignment with the organ-system structure of the curriculum.

This fragmentation created practical challenges for learners attempting to synthesize relationships among gross anatomy, embryology, histology, and clinical applications. Students frequently reported navigating multiple platforms to assemble a comprehensive understanding of anatomical relationships, a process that could introduce inefficiencies in studying while reinforcing disciplinary silos and introducing variability in content accuracy, depth, and alignment with course objectives.

Recognizing these challenges, BuckeyeView was conceptualized as an institutionally aligned educational hub designed to support integrated anatomy learning. The platform was envisioned as a complementary resource capable of linking anatomical structures with relevant sub-disciplinary and clinical concepts within a unified interface centered on interactive three-dimensional cadaveric models. Importantly, the development of such a platform required expertise spanning anatomical sciences, medical education, digital visualization, and instructional design.

For this reason, the project was intentionally developed through an interprofessional collaborative model. This collaborative structure allowed educational content, technological development, and user-experience considerations to evolve simultaneously throughout the design process.

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Interprofessional Development Process

BuckeyeView was developed using principles drawn from design-based educational research, emphasizing iterative development, feedback-driven revision, and alignment with curricular needs. Development occurred within the context of the competency-based UME curriculum at OSUCOM. From its inception, the project was structured as a student-driven, faculty-supported partnership, bringing together contributors from multiple disciplines to support both educational design and technical implementation.

The interprofessional team included medical students and doctoral trainees in anatomical sciences, faculty and technical specialists from the Advanced Computing Center for the Arts and Design (ACCAD) and OSUCOM, and undergraduate computer science students completing senior capstone projects. Additional consulting professionals contributed expertise in imaging workflows, software design, and instructional usability. This collaborative structure allowed individuals with complementary expertise to contribute to the development process while simultaneously gaining exposure to disciplines outside their primary field of training.

The collaborative model enabled educational development, technical platform design, visualization expertise, and user experience considerations to evolve concurrently. Regular interdisciplinary discussions allowed educators to communicate pedagogical priorities, while technical contributors translated those priorities into functional design features within the platform. Through this process, the project functioned not only as a tool for educational innovation but also as a learning experience for participants across disciplines. Figure 1 illustrates the student-driven, faculty-supported structure of the BuckeyeView development team and emphasizes the iterative exchange among educational, technical, visualization, and advisory contributors.

Design Principles and Platform Architecture

Platform development unfolded through several iterative stages designed to align technological capabilities with curricular objectives. Initial needs assessment occurred through consultation with faculty and students, which identified key challenges associated with integrative anatomy teaching within the existing curriculum. Educational design efforts prioritized anatomy as the initial domain of focus while intentionally incorporating connections to related foundational sciences. Content selection emphasized structures and concepts that would benefit from visual and spatial representation while supporting integration across anatomical subdisciplines.

Cadaveric specimens were prepared through targeted prosections conducted in the gross anatomy laboratory. Each prosection was selected to align with organ system-specific curricular learning objectives. Within the cardiopulmonary unit, for example, learning objectives included describing the gross anatomy and spatial relationships of cardiac structures and relating these to clinical findings, diagnostic testing, and pathophysiologic processes. Accordingly, a donor heart was explanted with the great vessels intact and sequentially dissected to expose the coronary arteries, internal cardiac chambers, and heart valves. Additional specimens with anatomic variants or pathologic changes were used for supplemental prosections. Together, these prosections allowed the creation of cardiac models intentionally mapped to curricular objectives, supporting student understanding of typical anatomy, anatomic variation, and clinically relevant pathologic changes.

Detailed photographic datasets were obtained following each sequential prosection to capture anatomic structures with sufficient resolution for digital reconstruction.

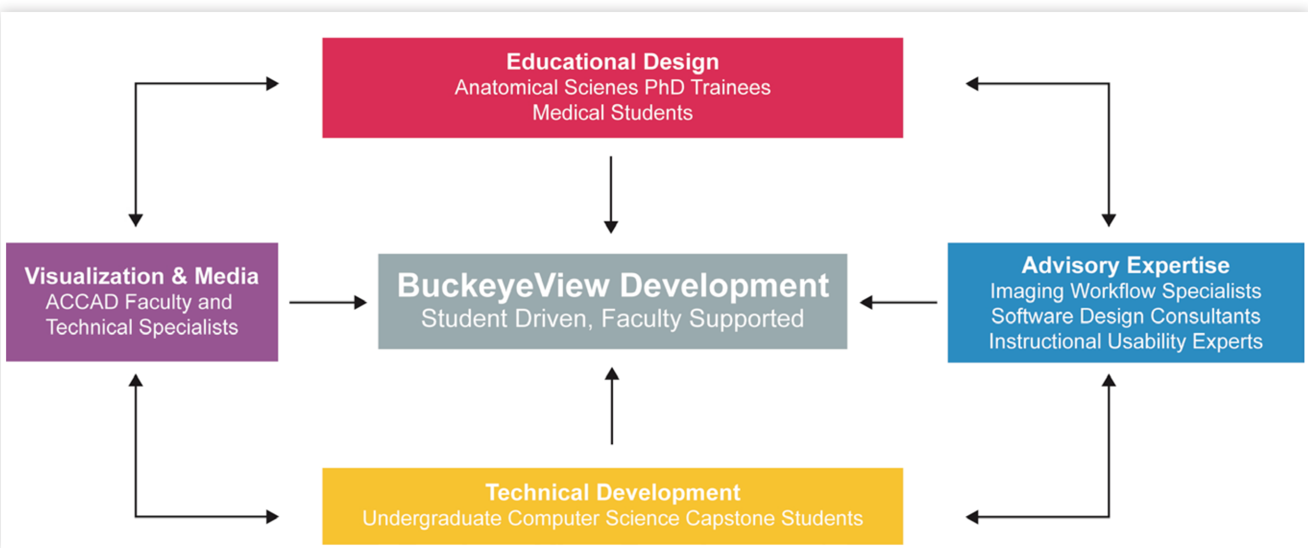

Figure 1. *Interprofessional structure of the BuckeyeView development team demonstrating the student-driven, faculty-supported collaboration among educational design, technical development, visualization and media, and advisory expertise contributors.*

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Photographs were captured from multiple angles and subsequently processed using photogrammetry-based reconstruction software developed by ACCAD collaborator Jeremy Patterson (Senior Graphics Researcher/Instructor ACCAD). The reconstruction process generates interactive three-dimensional surface models that can be embedded within the BuckeyeView platform. At the current stage of development, BuckeyeView models are generated from these photographic datasets and do not currently include supplementary sectional or radiologic imaging datasets, such as transverse, longitudinal, or oblique sectional images, CT, or MRI. Future platform development aims to incorporate anatomically relevant cross-sectional and radiologic correlates alongside individual cadaveric models, allowing learners to connect prosected anatomy with clinically relevant imaging perspectives.

The current platform allows learners to visually explore cadaveric anatomy through interactive manipulation of three-dimensional reconstructions, including rotation, zooming, and labeled structure identification, while also accessing guided learning features, quiz functionality, and linked content pages. At present, they are not intended to replace formal cadaveric dissection or function as fully segmented virtual-dissection models with organ removal or layer-by-layer reflection. Rather, the models serve as visual anchor points around which related educational content can be organized.

Within the platform interface, anatomical structures function as integrative nodes linking learners to related subdisciplinary concepts and relevant clinical applications.

This design distinguishes BuckeyeView from many existing free or commercial three-dimensional anatomy platforms by deliberately aligning cadaveric prosection-based models with the institution's curriculum, rather than serving as a general-purpose anatomy atlas. Specifically, BuckeyeView is designed around OSUCOM learning objectives and leverages cadaveric models to connect gross anatomy with embryology, histology, foundational science concepts, diagnostic interpretation, and clinical applications within a unified interface. This design supports a student-centered exploratory learning approach, allowing users to engage with anatomical structures through visual exploration while simultaneously connecting structural knowledge to underlying scientific principles and applied clinical contexts. Figure 2 summarizes these paired design elements by depicting both the BuckeyeView development workflow and the platform's integrative learning model linking three-dimensional anatomical structures to subdisciplinary, foundational sciences, and clinical content.

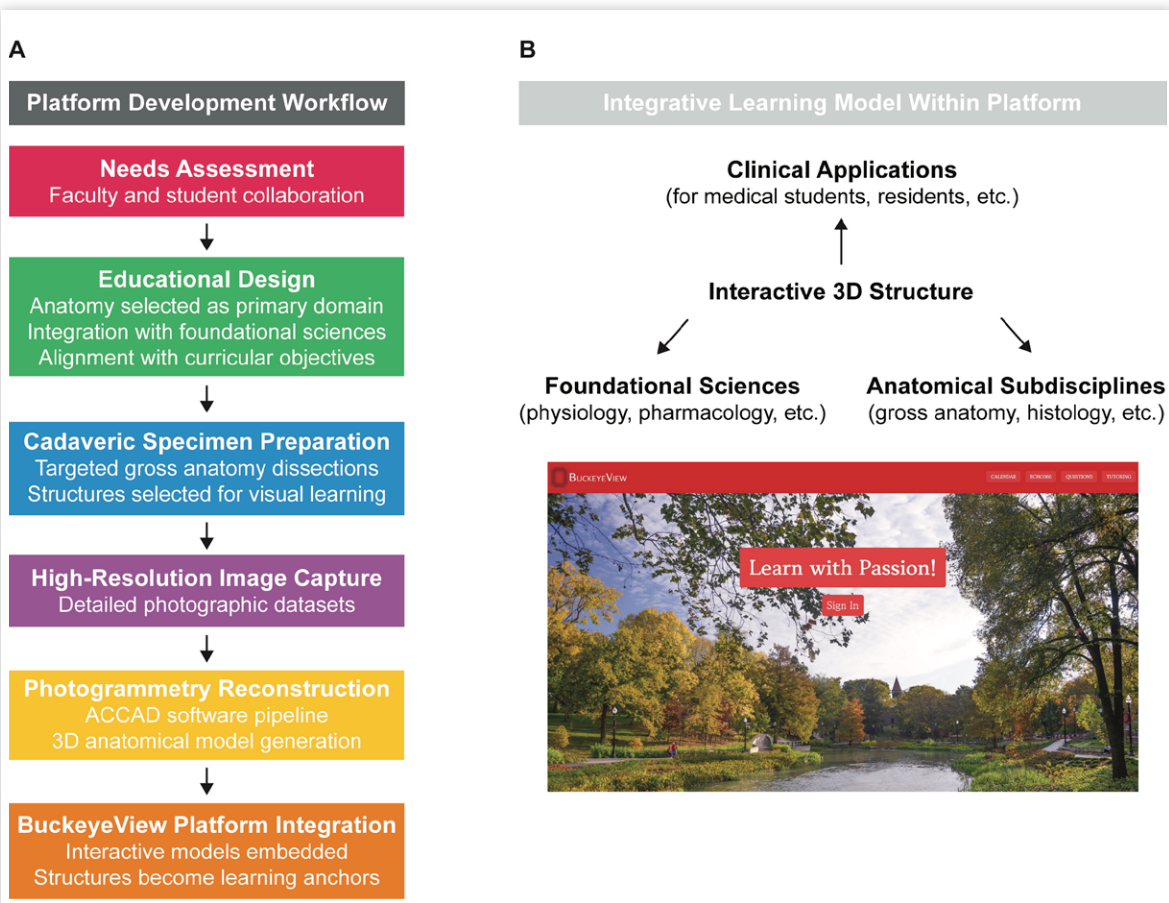

Figure 2. *BuckeyeView platform development workflow and integrative learning model. (A) Development workflow from needs assessment and educational design through cadaveric specimen preparation, high-resolution image capture, photogrammetry-based reconstruction, and web-platform integration. (B) Integrative learning model in which interactive three-dimensional anatomical structures serve as anchors linking anatomical subdisciplines, foundational sciences, and clinical applications.*

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Lessons from Interprofessional Educational Innovation

Lesson 1: Interprofessional Collaboration Accelerates Educational Innovation

To date, the development of BuckeyeView has involved approximately twenty student contributors, five staff members, and multiple additional consulting collaborators. Although the project currently operates without dedicated external funding, the collective effort of this interprofessional team has enabled continued progress.

One of the most significant insights gained from this process has been the value of cross-disciplinary collaboration in addressing complex educational challenges. Contributors from diverse backgrounds—including medical education, anatomical sciences, computer science, and digital visualization—brought unique perspectives to the design process. These perspectives often revealed opportunities for innovation that might not have emerged within a single disciplinary framework.

Collaboration with technical experts also highlighted how exposure to unfamiliar domains can expand the scope of educational innovation. For example, technical contributors working with photogrammetry and web-based model integration encountered project-specific challenges when adapting reconstruction workflows to complex cadaveric specimens, including irregular surfaces, overlapping structures, and the need to balance visual fidelity with usability in an online learning platform. These technical considerations influenced how specimens were selected, dissected, photographed, reconstructed, labeled, and embedded within BuckeyeView. Conversely, anatomy educators and student contributors helped technical collaborators understand which anatomical relationships, labels, and clinical linkages were most educationally relevant for medical learners. This reciprocal exchange allowed technical feasibility and pedagogical priorities to inform one another throughout development.

Overall, interprofessional collaboration represents both the practical mechanism through which BuckeyeView has been developed and a transferable model for educational innovation.

Lesson 2: Student-driven development promotes learner-centered design

Participation in the project also provided experiential learning opportunities for contributors at multiple levels of training. Students involved in the development process gained exposure to interdisciplinary problem-solving and applied technology development, while educators gained insight into how learners interact with emerging digital tools.

Because students played a central role in conceptualizing and developing the platform, learner perspectives remained a consistent influence on design decisions. Student developers were able to identify practical challenges encountered when studying topics within integrated curricula and translate those experiences into design features intended to support more efficient and meaningful learning. As one computer science student noted, "BuckeyeView was a practical application of classroom principles. As a student I related to the problem we were striving to solve. The experience with 3D models will be relevant in the workplace."

Lesson 3: Academic schedules create unique challenges for student-led projects

Despite the benefits of the student-faculty collaborative model, the development process also presented logistical challenges. Because much of the work was conducted by students with competing academic responsibilities, development timelines were occasionally slowed during periods of high academic demand, such as examination weeks, clinical responsibilities, and academic transitions.

The time required for model development varied substantially by anatomic region, specimen complexity, and team member experience; however, prosection was only one component of a broader workflow that also included image capture, photogrammetry-based reconstruction, model review, editing, labeling, and content integration. In parallel, development of a new web-based educational platform required iterative decisions regarding site architecture, model embedding, interactive functionality, labeling systems, linked content pages, guided learning features, and quiz functionality. These steps often required multiple rounds of trial, feedback, and revision as the larger team refined how models and educational content would be organized for learner use.

In addition, differences in technical ability and familiarity with UME among collaborators required intentional communication to ensure that design decisions aligned with educational priorities. These challenges required flexible timelines, clear task delegation, and recurring communication across the medical student, anatomy, and technical teams. Nevertheless, they were largely offset by the collaborative enthusiasm of the team and a shared commitment to improving anatomy education through innovative technological approaches.

Future Directions

BuckeyeView has recently entered an internal beta testing phase at OSUCOM while remaining under active development. Current testing involves anatomy faculty, anatomy graduate students, and medical students. Medical student testers include learners who were not directly involved in platform development, allowing the team to assess usability and clarity from the perspective of intended end users. These groups were selected to provide complementary perspectives on platform refinement:

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anatomy faculty and graduate trainees provide content-expert review of anatomical accuracy, labeling, and curricular alignment, while medical students provide target-learner feedback regarding usability, clarity, interactive functionality, guided learning features, quiz functionality, linked content pages, and perceived educational value.

Feedback from this internal testing phase will guide refinement of the platform interface, expansion of the three-dimensional model library, evaluation of user engagement and educational utility, and future integration with additional foundational science disciplines within the preclinical curriculum. More broadly, the BuckeyeView project highlights the potential of interprofessional collaboration as a model for educational innovation. By bringing together expertise from medical education, computer science, computational design, and digital visualization, the project demonstrates how interdisciplinary teams can contribute to the development of educational resources that align closely with institutional curricula while supporting evolving learner needs.

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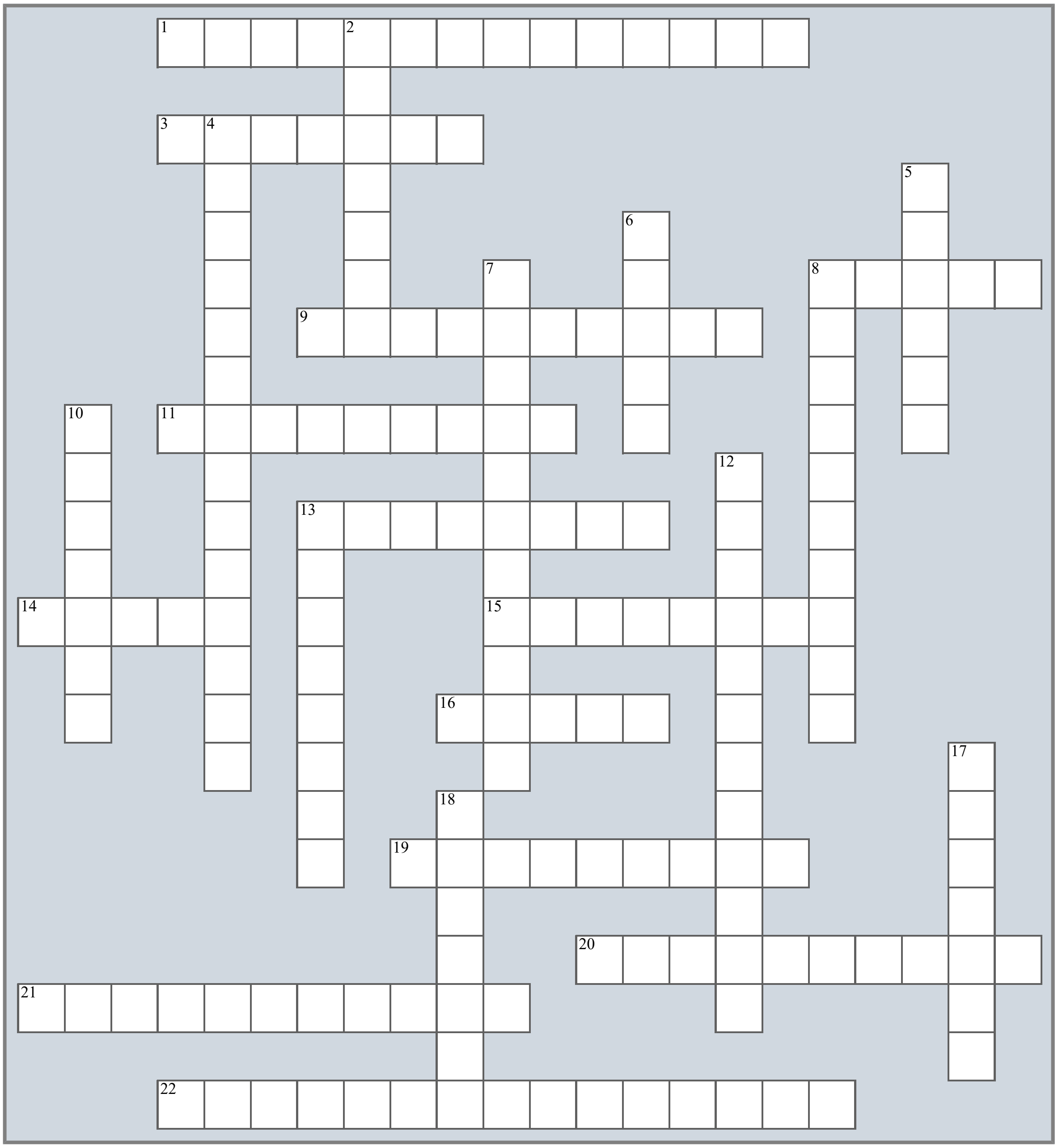
Back to TOC

HAPS Educator Crossword 8: Renal System

(For an online version CLICK HERE.)



ACROSS

1. Type of nephron that is primarily responsible for our ability to conserve water
3. Functional unit of the kidney
8. Singular of calices
9. Renal capillary bed where filtration occurs
11. Cells that compose the visceral layer of Bowman's (glomerular) capsule
13. In males, the urethra passes through the .... gland before approaching the penis
14. The inner wall of an empty bladder is collapsed into folds called ....
15. The .... arteriole branches off from the cortical radiate artery
16. Enzyme produced by granular (juxtaglomerular) cells that catalyzes the conversion of angiotensinogen to angiotensin I
19. Collecting duct cells that are involved in salt and water balance
20. The .... arteries can be found in the renal columns
21. The physiological term for emptying the bladder
22. Anatomical term used to describe the location of the kidneys

DOWN

2. The .... glands are located immediately superior to the kidneys
4. Hormone produced by the kidney that increases the rate of red blood cell production
5. Urine travels from the major calices through the .... to enter the ureter
6. The renal .... is an indentation that can be seen when looking at the kidneys from the outside
7. In terms of permeability, type of capillaries that support renal blood filtration
8. Urine enters the collecting ducts from the distal .... tubule
10. The outer covering of the kidney is called the renal or fibrous ....
12. Collecting duct cells that are involved in acidbase balance
13. The medullary or renal .... are where the collecting ducts are found.
17. .... arteries and veins indicate the boundary between the renal cortex and medulla
18. Inside the bladder, if you connect the openings for the two ureters and the urethra
18. The . . .. cells are the cells in the testis that produce testosterone
19. Stage at which an embryo begins to implant in the wall of the uterus
20. Hormone produced by Sertoli calls and granulosa cells that reduces FSH secretion

CLICK HERE for Answer Key

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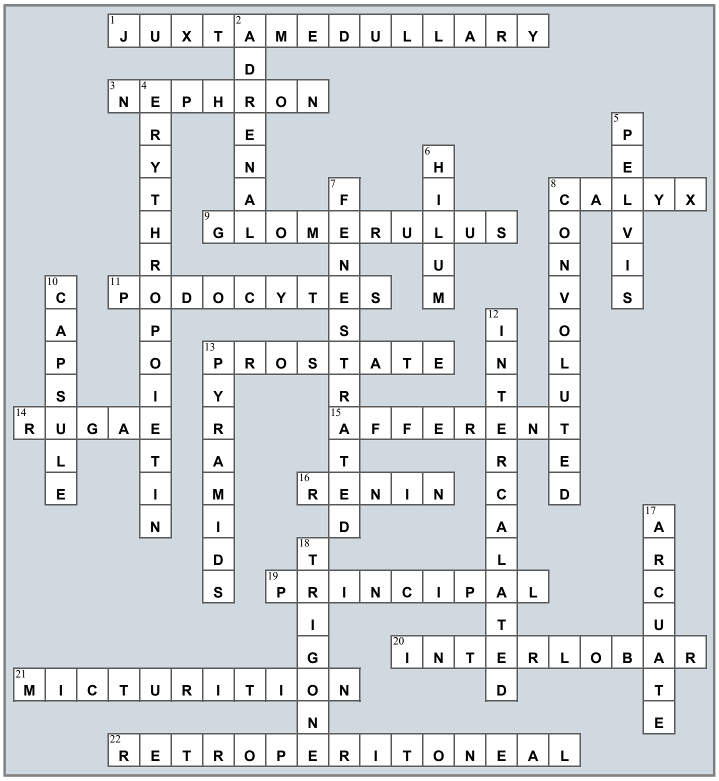
Answer key for: Crossword 8. Renal System (from previous page)



GO BACK to the puzzle

Back to TOC

Standing Committees:

2027 ANNUAL HOST COMMITTEE
Chad Wayne
This committee is in charge of coordinating the 2027 Annual Conference to take place in Houston, Texas

ANATOMICAL DONOR STEWARDSHIP
Jeremy Grachan
This committee is charged with developing, reviewing, and recommending policies and position statements on the use of cadavers for human anatomy and physiology education in colleges, universities and related institutions.

AWARDS & SCHOLARSHIPS
Gilbert Pitts
This committee recognizes talented HAPS Members through achievement awards, conference travel awards, and scholarships for HAPS-I.

COMMUNICATIONS
Caitlin Burns
This committee is tasked with helping HAPS establish its voice in a technological landscape shaped by social media. Committee members work closely with the Marketing Committee to facilitate connections within HAPS as well as recruiting potential members via social media.

CONFERENCES
Beth Eischen
This committee actively encourages HAPS members to consider hosting an Annual Conference. We provide advice and assistance to members who are considering hosting an annual conference.

CURRICULUM & INSTRUCTION
Currently Vacant
This committee develops and catalogs resources that aid in anatomy and physiology course development and instruction.

DIVERSITY, EQUITY, AND INCLUSION
Jennifer Stokes
This committee has the goal of creating spaces of belonging and accessibility for all members by embracing diversity and promoting equity and inclusion.

FUNDRAISING
Katie Salmeron
This committee supports HAPS and its members by seeking donations from those within the organization as well as external funding sources.

Click here to visit the HAPS committees webpage.

Special Committees and Programs:

EXAM PROGRAM LEADS
Valerie O'Loughlin
Dee Silverthorn
Janet Casagrand
This committee is a closed program managed by three Program Leads (Anatomy, Physiology, Anatomy & Physiology) that is charged with developing, maintaining, securing, and managing the HAPS standardized exams.

EXECUTIVE
Larry Young
Composed of the HAPS President, President-Elect, Past President, Treasurer and Secretary

FINANCES
Ron Gerrits

HAPS EDUCATOR
Jackie Carnegie, Editor-in-Chief
Brenda del Moral, Managing Editor
This committee is responsible for publishing spring, summer and winter editions of the HAPS Educator, the journal of the Human Anatomy and Physiology Society. The committee works closely with the Steering Committee and the President of HAPS.

NOMINATING
Chasity O'Malley
This committee recruits nominees for HAPS elected offices.

PRESIDENTS EMERITI ADVISORY COMMITTEE
Melissa Quinn
This committee consists of an experienced advisory group including all Past Presidents of HAPS. The committee advises and adds a sense of HAPS history to the deliberations of the BOD

STEERING
Abbey Kowynia
This committee consists of all committee chairs. It coordinates activities among committees and represents the collective committee activity to the HAPS BOD.

VIRTUAL PROGRAMMING
Currently Vacant
This committee is responsible for supporting, coordinating, and advancing HAPS virtual offerings.

WELCOMING AND BELONGING
Currently Vacant
This committee identifies opportunities for member recruitment, retention, and engagement that foster an inclusive and welcoming environment promoting professional and personal growth.

Back to TOC