HOW WE TEACH | Classroom and Laboratory Research Projects

Development of low-cost cardiac and skeletal muscle laboratory activities to teach physiology concepts and the scientific method

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Judge JL, Cazares VA, Thompson Z, Skidmore LA. Development of low-cost cardiac and skeletal muscle laboratory activities to teach physiology concepts and the scientific method. Adv Physiol Educ 44: 181–187, 2020; doi:10.1152/advan.00149.2019.—Anatomy and Physiology courses taught at community colleges tend to focus laboratory hours primarily on anatomy as opposed to physiology. However, research demonstrates that, when instructors utilize active learning approaches (such as in laboratory settings) where students participate in their own learning, students have improved outcomes, such as higher test scores and better retention of material. To provide community college students with opportunities for active learning in physiology, we developed two laboratory exercises to engage students in cardiac and skeletal muscle physiology. We utilized low-cost SpikerBox devices to measure electrical activity during cardiac (electrocardiogram) and skeletal muscle (electromyogram) contraction. Laboratory activities were employed in Anatomy and Physiology courses at two community colleges in southeast Michigan. A 2-h laboratory period was structured with a 20-min slide presentation covering background material on the subject and experiments to examine the effects of environmental variables on nervous system control of cardiac and skeletal muscle contraction. Students were asked to provide hypotheses and proposed mechanisms, complete a results section, and provide conclusions for the experiments based on their results. Our laboratory exercises improved student learning in physiology and knowledge of the scientific method and were well-received by community college students enrolled in Anatomy and Physiology. Our results demonstrate that the use of a SpikerBox for cardiac and skeletal muscle physiology concepts is a low-cost and effective approach to integrate physiology activities into an Anatomy and Physiology course.

INTRODUCTION

Anatomy and Physiology (A&P) courses at community colleges typically serve students who are pursuing careers in nursing or allied health sciences (3), or students who plan to transfer to a 4-yr institution to further pursue biology education. Community colleges also enroll high percentages of first-generation college, lower socioeconomic status, and underrepresented students in Science, Technology, Engineering, and Mathematics (STEM) (13). When A&P are taught in an integrated format, many community colleges in the state of Michigan structure their curriculum with physiology material being handled during lecture time, whereas anatomy is handled during laboratory. Thus little time is devoted to exploring physiology concepts outside of a lecture, especially for A&P I (see Fig. 1).

Many studies have shown that students in STEM courses, including physiology, learn best in an active learning environment compared with traditional lecture and passive dissemination of information (1, 3, 4, 10). An active learning environment is defined as one that encompasses methods of instruction that engage students in the learning process (12). Benefits of active learning include improved retention, improved test scores, and repair of misconceptions (3, 10). Furthermore, traditional lecture tends to lead to “memorization of facts,” as opposed to conceptual understanding in physiology (6).

Given the evidence for improved student outcomes surrounding implementation of active learning strategies and the lack of laboratory-based physiology activities in A&P courses at community colleges, we identified a needs gap, where community college A&P students would greatly benefit from hands-on active exploration of physiology concepts by conducting research experiments. To address this gap, we developed two physiology laboratory activities that could be integrated into the A&P curriculum at local community colleges (Henry Ford College in Dearborn, MI, and Wayne County Community College District in Detroit, MI). Considering that the costs of laboratory experiments are a common concern among community colleges, we sought to develop affordable laboratory activities with supplies that could serve multiple purposes. We focused on concepts that would integrate multiple organ systems and thus developed a skeletal muscle and a cardiac muscle physiology laboratory that examines nervous system control of muscle contraction. We utilized a SpikerBox device (Backyard Brains, Ann Arbor, MI) to obtain electrocardiogram (ECG) and electromyogram (EMG) recordings. SpikerBoxes are affordable at $150 per box, have many uses, and are currently being employed in educational and outreach settings with success (8, 14).

METHODS

Ethical Approval and Course Background

The study was deemed exempt by the Human Subjects Institutional Review Board at the University of Michigan under study ID HUM0051287. The study was conducted in A&P I and II courses at Henry Ford College in Dearborn, Michigan, and Wayne County Community College District, Northwest Campus, in Detroit, Michigan, in the Winter semester 2019. There were 109 students registered
for these classes, and 75% were female. Forty students completed the posttest for the cardiac muscle laboratory, and 37 completed the posttest for the skeletal muscle laboratory. Participants gave consent for the study, and all participant data were collected as anonymous data and maintained that way throughout the study. The classes are structured similarly at each school and generally transfer equivalently to 4-yr institutions. A&P I covers chemistry concepts, cellular and tissue organization, and the integumentary, skeletal, muscular, and nervous systems, whereas A&P II covers the special senses, metabolism, and energetics, fluid and electrolyte balance, and the endocrine, circulatory, lymphatic, respiratory, digestive, urinary, and reproductive systems. Lecture meets twice a week for 2 h, and laboratory meets once a week for 2 h. The skeletal muscle activity was delivered in A&P I, whereas the cardiac activity was delivered in A&P II. Henry Ford College A&P curriculum designates laboratory for anatomy instruction using models and does not use physiology laboratory activities. Wayne County Community College District curriculum designates all laboratories in A&P I as anatomy focused, and one laboratory in A&P II as a physiology experiment.

Institutional Profiles

Henry Ford College student demographics, as provided by the college, are as follows:

- **Age:** Average age is 25 yr, with 52% of the population being 21 yr and older.
- **Sex:** 54% are female (46% male).
- **Student enrollment status:** 67% are part time (33% full time).
- **On average, students enroll in 9 credit hours per term (A&P I and II are each 4 credit hours).**
- **62% attend day classes, 13% attend evening classes, 25% attend both.**

Wayne County Community College District student demographics, as provided by the college, are as follows:

- **Age:** Average age is 27 yr, with 59% of the population being 25 yr and older.
- **Sex:** 64% are female (36% male).
- **Student enrollment status:** 85% are part time (15% full time).
- **45% are first-generation college students.**
- **41.2% attend day classes, 22.3% attend evening, 21.2% attend both, and 15.3% utilize online courses.**

Laboratory Exercises

One instructor delivered an ~20-min slideshow presentation with background information on the subject matter and scientific method, and an overview of the experiments. Students were provided with a laboratory handout that recapitulated information in the slideshow and described the methods for the experiments. The laboratory activities were developed using the Heart and Brain SpikerBox device purchased from Backyard Brains (Ann Arbor, MI). The SpikerBox ships with all necessary supplies for these experiments, including a 9-V battery and 12 electrodes. Recurring costs for running the laboratory a second time would include purchasing additional electrodes (Backyard Brains sells 100 for $29.99, or elsewhere for similar pricing). Electrical recordings were made using the free Backyard Brains open-source software, Spike Recorder (for use on a laptop) or the Spike Recorder app (on mobile devices).

For each experiment, students were given a prompting question to guide their thinking about the experiment, were asked to provide a hypothesis, complete a results section, and make conclusions about the results. Instructors worked with groups to stimulate group discussions surrounding hypotheses and proposed mechanisms. While students worked in groups for the experiments, they were encouraged to develop their own hypotheses, and, frequently, group members’ hypotheses and proposed mechanisms did not agree. For each laboratory session, students worked in groups of two to six. A small group size was defined as less than four students, and a large group size was defined as greater than four students. Three instructors helped to guide students through the experimental setup and software as needed.

Skeletal Muscle Laboratory Experiments

Complete laboratory exercises, review materials, and introductory slideshow presentations have been deposited to figshare.com and can be freely accessed online (all supplemental material is available at https://doi.org/10.6084/m9.figs.share.c.4714118).

**Goal.** The goal of these exercises is to use the scientific method to understand how muscle contractions relate to electrical activity by nerve cells. **Objectives.** By the end of this activity, you should be able to:

**A.** Name the steps of the scientific method.

**B.** Explain what an EMG measures and what it can be used for.

**Exercise 1: Muscle in rest versus in contraction.** **PROMPTING QUESTION(S).** What is the relationship between electrical activity and muscle contraction? Is the amplitude and frequency of an EMG signal higher during muscle rest or contraction?

**ACTIVITY.** Record an EMG of a subject by placing two red electrodes on his/her forearm and one black electrode on his/her opposite wrist. First, record a rest period of 30 s and then while the subject is contracting his/her forearm muscles by squeezing a hand grip as hard as he/she can for 10 s. Repeat this a few times with different subjects. Compare and contrast the EMG recordings at rest and during contraction in relation to amplitude and frequency.

**Exercise 2: Muscle fatigue.** **PROMPTING QUESTION(S).** What will happen to electrical activity (amplitude and frequency) when a person (and their muscles) become tired or fatigued, and what will the EMG recording look like?

**ACTIVITY.** Record an EMG of a new subject by placing two red electrodes on his/her forearm and one black electrode on his/her opposite wrist. Ask the subject to contract his/her forearm muscles by squeezing a hand grip as hard as he/she can for 2 min or until he/she is fatigued. Record an EMG throughout this whole time. Repeat a few times with different subjects. Compare and contrast the EMG record-
understand how heart contractions relate to electrical activity.

Cardiac Muscle Laboratory Exercises

Goal. The goal of these exercises is to use the scientific method to understand how heart contractions relate to electrical activity.

**Exercise 1: Running in place.** PROMPTING QUESTION(S). What will an ECG recording show before and after running in place?

ACTIVITY. Record an ECG during a rest period for 2 min and log the heart rate on the graph labeled “Before Exercise.” Ask the subject to run in place for 1–2 min and start recording an ECG immediately after he/she stops; continue recording for 2 min. Log the heart rate immediately after exercise on the other graph. Record an ECG 2 min after the previous ECG (~4 min after the subject stopped exercising) and log the heart rate on the graph.

Exercise 2: Hold your breath. PROMPTING QUESTION(S). What will an ECG recording show before and after holding your breath?

ACTIVITY. Record an ECG for 2 min at rest and log the subject’s heart rate on the graph labeled “Before Breath Hold.” Ask the subject to hold his/her breath as long as he/she can and record an ECG throughout this whole time. Log the subject’s highest heart rate during this period above “During Breath Hold.” Record an ECG of the subject’s heart rate 2 min after breath hold. Log the heart rate on the graph above “2 Minutes After Breath Hold.”

Learning Assessment

Students’ knowledge regarding the scientific method and general background information about muscle physiology were examined by administration of a pre- and posttest of eight multiple-choice questions with four possible answers, and a short-answer question worth two points. Our goal was not only to achieve learning in the content area (skeletal or cardiac muscle physiology), but also to reinforce scientific method. Therefore, some of our background information and questions were related to the application of the scientific method. Pretests were administered after receiving consent from students and before any presentation of material. Posttests were administered after students had completed the last activity and summarized their results. Questions were identical on the pretest and posttest.

**Students’ Knowledge Regarding the Scientific Method**

**Learning Assessment**

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Student Perceptions

Students’ perceptions of the laboratory activities were evaluated using a separate set of nine questions with responses on a Likert scale. Potential responses included strongly disagree, disagree, neutral, agree, and strongly agree. The last question was a free response and asked for any additional comments or feedback regarding the activity.

Statistical Analyses

Pre- and posttest scores were generated by scoring the student responses on nine questions. Questions 1–8, worth 1 point, were multiple-choice style and contained only one possible correct answer. Question 9 was a 2-point short-answer question that prompted students to name as many of the steps of the scientific method as they could remember. To score question 9, researchers assessed whether the student’s response fell into one of five categories: observation/question, hypothesis, experiment/collection data, analyze data/make conclusions, accept/reject hypothesis. A student received 0.4 points for each response that could reasonably fall under one of these categories and could earn up to 2 total points. To enhance reliability of scoring, the data were scored independently by two of the authors. Any scoring discrepancies for open-ended questions were resolved by consensus. Subsequent statistical data analyses and plotting was done in R Studio (https://www.R-project.org) using open-source packages (e.g., Refs. 11, 16, 17) and custom-written scripts. Statistical analyses employed were either independent samples t test or multifactor analysis of variance (ANOVA) for parametric data, including between- and/or within-subjects factors. Specifically, for the analysis of pre/posttest performance that was grouped by group size or college, a multifactor ANOVA was employed. For further interrogation of statistically significant ANOVA effects, post hoc Tukey’s t tests for multiple comparisons were carried out, as indicated in the text.

RESULTS

We surveyed nine community colleges in Michigan by e-mailing a member of their Biology Department with two questions regarding their A&P classes: 1) Out of all your laboratory class periods for A&P I in a semester, how many are dedicated to physiology-related activities or experiments?; and 2) Out of all your laboratory class periods for A&P II in a semester, how many are dedicated to physiology-related activities or experiments? Two of the colleges split their A&P classes so that semester 1 only has anatomy laboratories and semester 2 is mostly or all physiology activities. The other colleges integrate anatomy and physiology during a semester, and have from zero to five physiology-related laboratory activities each semester. Overall, physiology activities account for less than one-half of scheduled laboratory activities at eight out of the nine schools (Fig. 1).

Overall, student knowledge significantly improved following completion of the skeletal [pretest mean (M Pre) = 6.9, SD = 1.99 versus posttest mean (M Post) = 8.14, SD = 1.39; t(17) = 8.14, SD = 1.39; * p < 0.0001). The electrocardiogram (ECG)/electrocardiograph (ECG) and magnetic resonance imaging (MRI) were most frequently selected as the device that records electrical activity of muscle, while the defibrillator and ultrasound were the least selected. While other devices were selected less frequently, they were still selected by a large percentage of students. The defibrillator was selected by 13% of students, while ultrasound was selected by 43%. The other devices selected were the electrocardiograph (ECG) (6%), defibrillator (13%), and magnetic resonance imaging (MRI) (19%). The question was asked as a free response and asked for any additional comments or feedback regarding the activity. The last question was a free response and asked for any additional comments or feedback regarding the activity.

Fig. 3. Muscle physiology laboratories enhance understanding of the scientific method and the function of the electrocardiogram/electrocardiograph. A question-by-question statistical analysis was used to analyze student performance on specific concepts. Questions 1–5 (A–E, respectively) and question 9 (F) either refer to the scientific method or to general muscle physiology and appeared in both cardiac and skeletal muscle laboratories; therefore, data for these questions were collapsed to include participants from both activities. Analysis implemented was multifactor ANOVA (factors: test time, question number) with post hoc Tukey’s t test for significant main effects. A–F: results for each of these questions as a mean proportion of correct answers (left) and a distribution of selected answers (as percent selected, right). *Statistical analyses revealed significant knowledge gains for question 2 (B; p < 0.05), question 5 (E; p < 0.01), and question 9 (F; p < 0.0001). Pre, pretest; Post, posttest.
scores between pre- and posttest \( t(74) = 3.03, P = 0.003 \) and cardiac muscle \( [M_{\text{pre}} = 5.45, \ SD = 1.88 \text{ versus } M_{\text{post}} = 7.63, \ SD = 1.39; \ t(82) = 5.53, P < 0.001] \) laboratory activities as indicated by pre- and posttest score comparisons (Fig. 2, A and B). To assess if group size affected learning gains, we compared pre- and posttest scores in small- versus large-group sizes for each laboratory (Fig. 2, C and D). As before, we found a significant increase in test scores between pre- and posttest [skeletal: \( F_{(1,38)} = 7.55, P = 0.009; \) cardiac: \( F_{(1,38)} = 13.30, P < 0.001 \), but no statistically significant effect of group size [skeletal: \( F_{(1,38)} = 0.72, P = 0.40; \) cardiac: \( F_{(1,38)} = 3.79; P = 0.06 \]. Next, we assessed the effectiveness of the laboratories by grouping participants based on the college in which the physiology activity was conducted (Fig. 2, E and F). Interestingly, for the cardiac muscle laboratory (Fig. 2E), we found a main effect of college [cardiac: \( F_{(1,38)} = 41.09; P < 0.001 \). The effect of college in the cardiac laboratory is explained by a significant difference in mean pretest scores between the colleges (college A: mean = 6.6, SD = 1.37; college B: mean = 3.9, SD = 1.25). College B (see Fig. 2E, “Pre”), which had not received the in-class lecture material on the cardiac conduction system before participating in the laboratory, scored significantly lower on the pretest exam \( t(76) = 5.48, P < 0.001 \). Nonetheless, despite differences in pretest score, implementation of the laboratory activity resulted in a significant gain in knowledge between pre- and posttest [cardiac: \( F_{(1,35)} = 53.30; P < 0.001 \]. Consistent with this finding, we found no main effect of college on test scores for the skeletal muscle activity \( [F_{(1,35)} = 0.0, P = 0.958] \) in which participants from both campuses received in-class lecture material before participating in the laboratory (Fig. 2F). Furthermore, students from both colleges showed significant knowledge gains between pre- and posttest [skeletal: \( F_{(1,35)} = 5.25, P = 0.02811 \].

To analyze student performance on specific concepts, we conducted a question-by-question statistical analysis. Questions 1–5 and 9 were general questions about electrical activity or referred to the scientific method and appeared in both cardiac and skeletal muscle laboratories; therefore, data for these questions were collapsed to include participants from both activities (Fig. 3). Using a repeated-measures ANOVA, we found statistically significant main effects for test time [pre vs. post: \( F_{(1,38)} = 34.49; P < 0.001 \], question number \( [F_{(5,190)} = 49.24; P < 0.001 \) and a significant interaction between the factors \( [F_{(5,190)} = 8.29; P < 0.001 \]. To explore the interaction between test time and question number, we carried out post hoc pairwise comparisons between pre- and posttest scores for each question. Post hoc analyses revealed statistically significant knowledge gains for question 2 [Fig. 3B, \( t(226) = 2.87, P = 0.004 \).
0.004], question 5 [Fig. 3E, t_{(226)} = 2.87, P = 0.004], and question 9 [Fig. 3F, t_{(226)} = 7.05, P = 0.001].

To analyze student performance on the three questions that were unique to each laboratory (questions 6–8), we used a separate repeated-measures ANOVA for each laboratory. Students showed statistically significant improvement in test scores on cardiac muscle-specific questions [Fig. 4, A–C, F_{(1,40)} = 37.56; P < 0.001]. There was no significant difference between pre- and posttest scores for questions 6–8 on the skeletal muscle activity [Fig. 4, D–F, F_{(1,37)} = 1.55; P = 0.22].

Finally, to assess the students’ experience and opinions of the laboratory activities, we administered an eight-question survey using a Likert scale (see Fig. 5). Generally, students expressed positive views about the laboratory activities, with all questions receiving ≥64% for “strongly agree” responses (Fig. 5). Students were also given the opportunity to add any additional comments or feedback. Some sample responses included:

“I enjoyed this activity a lot. I much prefer hands-on labs.”

“This helped [me] to understand the amplitude and frequency more during muscle contractions.”

“The activity was helpful because it was hands on and we were able to see the information/material happen in our own bodies.”

“I enjoyed the lab experiments and they helped me with understanding the lectures.”

**DISCUSSION**

After surveying community colleges in Michigan (Fig. 1), we identified a need for physiology activities in A&P laboratories. Therefore, our goal was to develop cost-effective laboratory activities that can readily be employed in Introductory Physiology courses, and to reinforce application of the scientific method. We utilized SpikerBox devices to measure electrical activity of cardiac and skeletal muscle in our laboratories. Overall, our results demonstrate that we developed two physiology laboratory activities that improved student learning (Figs. 2–4) and that were well-received and enjoyed by students (Fig. 5).

We tested our laboratories at two community colleges in southeast Michigan. Both colleges serve similar demographics of students and similarly structure their A&P courses. While we sought to keep group sizes consistent, group sizes varied between two and six students, depending on the number of students per laboratory section and attendance. However, our results demonstrate that improved knowledge occurred independent of group size (Fig. 2, C and D). We also assessed performance of students at each of the colleges, and we found significant learning gains, irrespective of which college the activity was carried out in (Fig. 2, E and F). Interestingly, one of the laboratory activities was carried out for a group of students who had not received the corresponding in-class lecture material (Fig. 2, pretest score in college B). Not surprisingly, this group scored lower on average during the pretest than the equivalent group in college A; nonetheless, they achieved significant learning gains after the laboratory activity (Fig. 2E). This suggests that the laboratory activities described here may be effective learning tools, independent of when lecture material is delivered.

Through their survey of community college A&P instructors’ attitudes, Lunsford and Herzog (7) describe a need for “concrete applicable approaches” to provide students with hands-on experiences for learning. Community college students taking A&P commonly enter into career training programs that require an understanding of physiology concepts for clinical applications. Our laboratories provide hands-on opportunities for students to get exposure to techniques and appli-
cations used in clinical settings. In particular, our results showed specific knowledge gains in the understanding of the function of an EMG or ECG. Furthermore, the muscle physiology laboratory exercises could be easily used during lecture periods (do not require a “wet lab”) or integrated laboratory and lecture A&P courses, which have been shown to enhance student performance (3, 9).

Community colleges are also faced with a challenge in promoting degree attainment for students. For example, a national survey of students enrolling in a community college during the fall of 2010 found that, 6 yr later, 45% had left higher education without a degree of any kind [compared with 24% at 4-yr institutions (15)]. Moreover, community colleges enroll higher percentages of first-generation, lower socioeconomic status, and underrepresented students in STEM compared with 4-yr institutions (13). A study of programs that were successful in enhancing retention or persistence among underrepresented minority students in STEM found that they employed three common interventions: 1) early research experiences, 2) active learning in introductory courses, and 3) membership in STEM learning communities (5). The design of these laboratory activities was intended to introduce students to research methods using hands-on approaches and to employ active learning techniques to enhance learning of physiology concepts. Consistent with these goals, students in this study self-reported that they enjoyed using the scientific method for physiology activities and that it helped them in learning difficult concepts. This is consistent with at least one previous study in which students identified in a questionnaire that laboratory activities gave them a more concrete idea of the learning content and enhanced their ability to remember it (2).

Altogether, we find that use of these laboratory activities on muscle physiology is an effective tool for enhancing student learning through the use of active learning curriculum.

Limitations of the Study

The overall goal of this study was to assess how newly developed laboratory activities impact student learning and to examine the student’s opinions of the laboratories. To achieve this, this study compared student performance on a 10-question quiz for individuals before and after the laboratory activities. While this design permits assessment of knowledge gains, it is not able to evaluate if this added curriculum enhances student learning relative to administering lecture material only. Furthermore, this study used a short assessment format (only 9 questions). Particularly, for the skeletal muscle laboratory activity, students exhibited relatively high pretest scores, which indicates that a more difficult and extensive test could be used. Future directions for this study include long-term assessment (weeks to months) of student knowledge to test if those who participate in the active learning laboratories exhibit better retention of class material. In addition, assessment tools could be enhanced to include higher-order questions in Bloom’s taxonomy (i.e., comprehension and application questions). Despite these limitations, the overall goal of this study to assess learning and student opinions in response to these muscle physiology laboratory activities was met.

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