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Introduction of Active Learning Techniques Increases Student Learning in a Systems Physiology Laboratory Course

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Abstract

Many laboratory courses focus on teaching experimental techniques and often do this by providing step-by-step protocols for students to follow. While this technique exposes the students to hands-on experiences and allows them to learn in a controlled environment, it does not always promote a deep understanding of the material because the students fail to construct knowledge. To address this, the sophomore-level systems physiology laboratory course has been recently modified to include more active learning.

The systems physiology laboratory course is structured around measuring common physiological signals, including EMG, EEG, ECG, and pulmonary function. Students work in groups and use BIOPAC hardware and software to record and analyze these signals. Without changing the content of the class or the equipment used, active learning was introduced in 2013 at three different stages of the class:

1. *Before lab*: An extra lab session was offered to one team of students per section per week to develop their capacity to be peer-leaders. These students worked in groups to gain an in-depth understanding of the material to be covered the following week in lab.
2. *During lab*: The peer-leaders present a short lecture covering the necessary background information. Additionally, they serve as 'experts' helping their peers troubleshoot and complete the lab activities.
3. A*fter lab*: Peer-leaders write a modified in-lab protocol with detailed instructions on how to implement a new laboratory activity that reinforces the concepts learned in class. This assignment allows the students to synthesize the knowledge gained in order to develop new ideas. The resulting protocols could also be used in the future to supplement the in-lab activities.

The impact of these activities was assessed using course grades and a knowledge test given at the end of the semester. Test results show a higher average grade for students that participated in active learning activities when compared to the students that learned the material in a conventional way without participating in the peer-leader sessions. Average course grades also show an increase after active learning techniques were implemented, suggesting that active learning techniques contribute to student learning in the systems physiology laboratory course.

Introduction to Active Learning Techniques

Active learning is characterized by the introduction of instructional activities that engage students in their own learning process[1]. A wide variety of instructional methodologies fall within the active learning category as long as they provide the students with "opportunities to meaningfully talk, listen, write, read and reflect on the content, ideas, issue, and concerns of an academic subject" [2]. Some of these activities, such as collaborative learning and peer-teaching have shown to improve not only content knowledge but also student engagement when compared to traditional lecture courses[3-5].

The active learning techniques used in this study are briefly defined below:

Collaborative learning describes instructional methods that encourage students to work in small groups to achieve shared learning goals. Groups work together to complete a specific task and are formed on the basis of cooperation and support amongst the group members. Research has shown that collaborative learning improves academic achievements, student attitudes, and student retention[6-9].

Peer-teaching is based on the premise that learning-by-teaching positively affects the students' cognitive and behavioral characteristics. In order to teach, students are first required to go through the teaching process (prepare, present and assess the material), which helps them achieve a more in-depth understanding of the material (rather than just memorizing information). Since teaching requires a basic understanding of the material and a plan for conveying this material, teachers often learn by (a) reviewing: working with the material while preparing to teach another, and (b) reformulating: organizing the content in a meaningful way that associates the material with what the student already knows. Research suggests that learning by teaching also helps improve communication skills and that it provides the students with an opportunity to experience realistic social interactions while applying their content knowledge in an appropriate learning environment[5, 10].

Description of the Systems Physiology Laboratory

The Systems Physiology Laboratory Module (BIOE 320) is a required sophomore-level course for bioengineering students. The course typically enrolls 40-50 students and is offered every spring semester. The Systems Physiology Lab is structured around measuring common physiological signals, including Electromyography (EMG), Electroencephalography (EEG), Electrocardiography (ECG), and pulmonary function tests using BIOPAC hardware and software.

The objectives of this course are:

1. To use engineering tools and biomedical instrumentation to record different physiological signals from human beings.
2. To analyze and interpret these acquired data and understand their physiological relevance.
3. To recognize the importance of signal to noise ratio in physiological measurements.
4. To apply basic engineering concepts to the analysis of physiological measurements.

Students explore physiological concepts through computer simulations, data collection, and engineering analysis. During lab, students work in pairs recording and analyzing their own physiological signals and monitoring how baseline levels change when exposed to different conditions (e.g., exercise, hyperventilation, body posture). These activities help the students gain a better understanding of human physiology through experimentation.

The BIOE 320 course is currently divided into 10 laboratory sessions; each session covers a different content topic (Table 1). In order to maintain the number of students to a minimum, this course is divided into smaller groups called sections (4 sections per week). All the sections cover the same topic at any given week, but different students attend lab on a different day

(Monday, Tuesday, Wednesday, or Thursday). Prior to coming to lab, students are responsible for completing an individual pre-lab assignment that covers basic background information that helps prepare the students for the lab activities.

Table 1. Topics covered in the different laboratory sessions of BIOE 320

Session	**Topic**
1	Intro to BIOPAC
2	EMG I: Reflex
3	EMG II
4	EEG
5	ECG I
6	ECG II
7	Blood Pressure
8	Pulmonary Function I
9	Pulmonary Function II
10	Basal Metabolic Rate

Each afternoon section is divided in two parts: the lecture and the hands-on lab component. The first part of the lab includes a 15-20 minute lecture covering the physiological background and technical material that the students need to know to complete the in-lab activities. The second block of the lab lasts 2-3 hours and consists of students working in pairs to collect and analyze data for the in-lab activities. At the end of the lab session each pair of students turns in an in-lab report that includes the data analysis performed in lab, as well as answers to questions designed to encourage the students to use engineering tools to interpret the physiological signals measured. After lab, each individual completes a post-lab assignment in which he/she performs advanced data analysis and/or draws further conclusions from the in-lab activities performed.

Implementation of Active Learning Techniques to BIOE 320

Without changing the content of the class or the equipment used, active learning was introduced in 2013 at three different stages of the class (Figure 1):

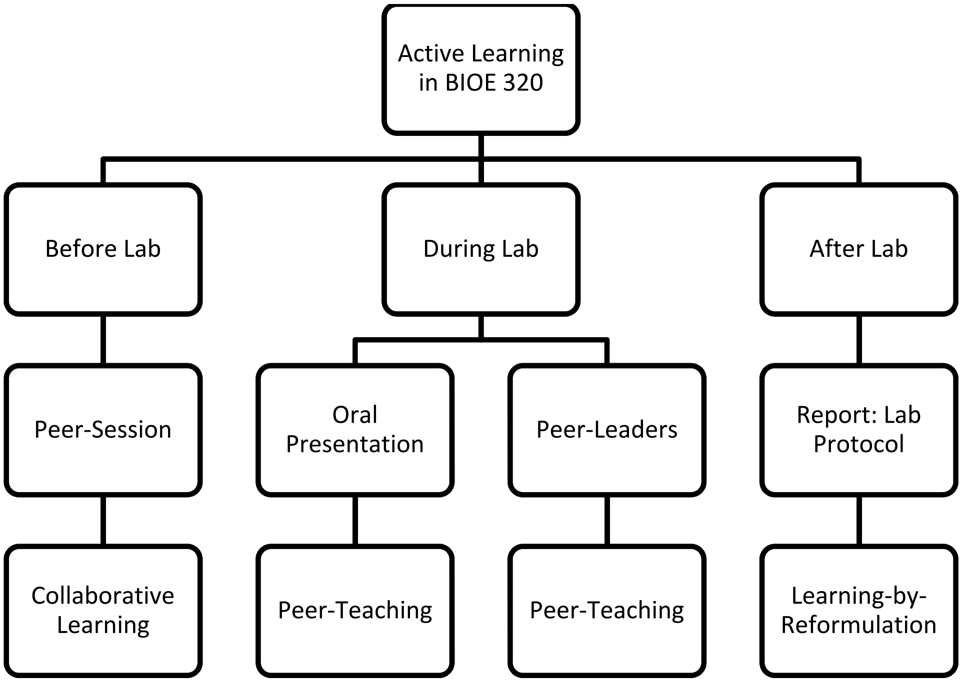

Figure 1. Summary of active leaning techniques and/or acquired skills that result from the changes implemented to BIOE 320 during 2013.

1. *Before lab*: In addition to the 4 sections offered every week, an extra lab session (*peer-session*) was offered to one team of students per section per week to develop their capacity to become peer-leaders. Every student in the course was able to participate in one peer-leader session throughout the semester. During the peer-session, the students work in groups to gain an in-depth understanding of the material to be covered the following week in lab. A sample of the schedule can be seen in Table 2, showing that the scheduled peer-session meets ahead of the regular lab session for the same content topic. Each peer-session consists of 6-8 students (3-4 teams, one from each section) that work in pairs to acquire data, but collaborate as a larger group asking and answering each other questions and discussing the higher-order concepts required to complete the laboratory activity. This activity helps involve the students in their own learning process and contributes to collaborative learning.

Table 2. Sample of Scheduled Lab Activities for BIOE 320. Peer-session generally takes place the week before the corresponding content topic is covered in the regular lab session.

Session	Content Topic	Peer- Session	Regular Lab Schedule
3	EMG II	Jan 22	Jan 28 – Feb 1
4	EEG	Jan 29	Feb 4 – Feb 8

2. *During lab*: At the beginning of the lab session, the peer-leaders present a short lecture covering the necessary background information. (Before 2013 this presentation was done by the

instructor.) The mini-lecture covers all the necessary information to complete the in-lab activities and understand the physiological relevance of the data acquired during lab and is divided in two parts: physiological background and equipment set-up. This student-led presentation is evaluated by the instructor, teaching assistant and peers and is followed by a question & answer session. The presentation grade counts as a small percentage of the final course grade, but is also used as a mechanism to provide feedback to the students about the content and style of their presentation. After the mini-lecture, the peer leaders go around the lab and serve as 'experts' helping their peers troubleshoot and complete the in-lab activities. The peer-leaders do not replace the instructor, but serve as the first point-of-contact for other students, promoting peer-learning and decreasing the amount of time the students spend troubleshooting minor equipment problems (i.e. students are more likely to ask for help from their peers than from the instructor) [11, 12]. While peer-leaders help with equipment set-up and basic troubleshooting, the graduate teaching assistant and the instructor are allowed extra time to discuss higher-order concepts with other students.

3. A*fter lab*: Each group of peer-leaders (i.e. 2 students) works to modify the in-lab protocol in order to include (1) physiologically-relevant background information, (2) step-by-step instructions on how to set-up equipment and perform physiological measurements, and (3) an extra lab activity, using the equipment available, that helps clarify or reinforce a physiological concept learned in class. Currently, the in-lab protocol provided to the students includes only basic instructions on how to complete the lab activities and does not contain any of the background information required to understand the lab, thus in order to modify this protocol the students are required to identify the relevant information and rewrite this document to include clear and concise background information and lab instructions. The goal of this assignment is to provide the students with the opportunity to work on higher-order thinking skills by synthesizing the knowledge gained in order to develop new ideas (i.e. prioritize the information that should be included in the document, design and plan a new experiment). This assignment was graded by the instructor and feedback was provided to the students both on technical content and writing style. In future years, these documents can be used by the instructor to develop a more detailed lab protocol and/or supplement the in-lab activities.

Evaluation of Changes Introduced to BIOE 320

The impact of the active learning activities implemented to BIOE 320 was assessed using course grades and a knowledge test given at the end of the semester.

Average grades from 2011 (before active learning was introduced to BIOE 320) and 2013 were compared in the three types of assignments the students completed during the semester: 9 pre-labs, 10 in-labs and 10 post-labs. Pre-lab, in-lab and post-lab assignment were not changed from 2011 to 2013. Grading was done by teaching assistants using the same grading rubrics in both years. Average overall grades for all the assignments were also calculated and compared. A paired student's t-test showed a statistically significant increase ($p<0.05$) in average grades for all three types of assignments (pre-lab, in-lab and post-lab) after active learning was introduced (Figure 2). Overall assignment grades also show a statistically significant increase ($p<0.01$) from 83 ± 8% in 2011 (n=47) to 90 ± 5% in 2013 (n=50).

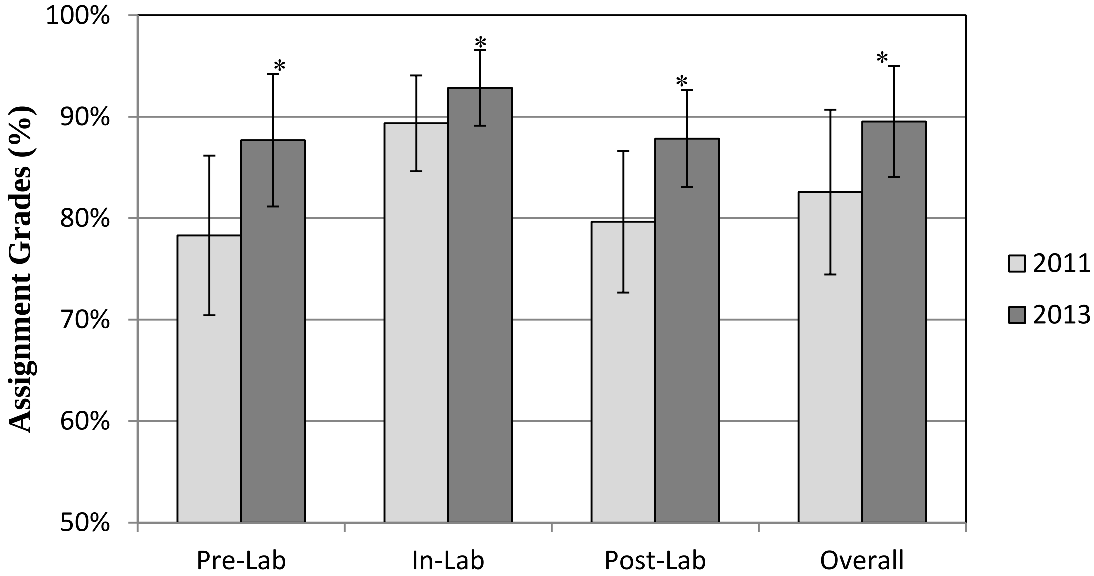

Figure 2. Average grades for pre-lab, in-lab, post-lab and overall assignments show a statistically significant increase (* $p<0.05$) after the introduction of active learning techniques to BIOE 320. Data represents mean ± standard deviation of assignment grades for all the students registered for BIOE 320 in 2011 (n=47) and 2013 (n=50).

At the end of the course, students registered for BIOE 320 in 2013 completed a knowledge test that included questions that evaluate common misconceptions from all the different topics covered throughout the course. Each student obtained 2 grades: an average grade for the questions that covered the topic where he/she served as a peer-leader and a grade for the rest of the questions (questions from all the sessions where the student did not participate in active learning activities). The score obtained in this test was not included in the final course grade calculations and students were instructed not to study for the test in order to monitor the amount of information that they retained rather than study habits. A paired student's t-test showed a statistically significant increase in the average grade for the questions corresponding to topics where students were involved in active learning activities, when compared to the average grade obtained from questions that covered topics learned in a conventional way without participating in the peer-leader session (67 ± 31% compared to 51 ± 15%, $p<0.01$).

Additionally, students were asked to select from the list of 10 lab topics covered during the semester the lab where they felt they learned the most and the lab where they learned the least. The results were matched to the lab where each student served as a peer-leader. Thirty-seven percent of the students (n=38) selected the lab where they used active learning as the lab where they learned the most, whereas none of the students selected the lab where they used active learning as the lab where they learned the least. Furthermore, when the students where asked if the peer-session helped them gain a better understanding of the material, improve their writing/presentation skills or develop their troubleshooting skills, 84% agreed or strongly agreed (Figure 3).

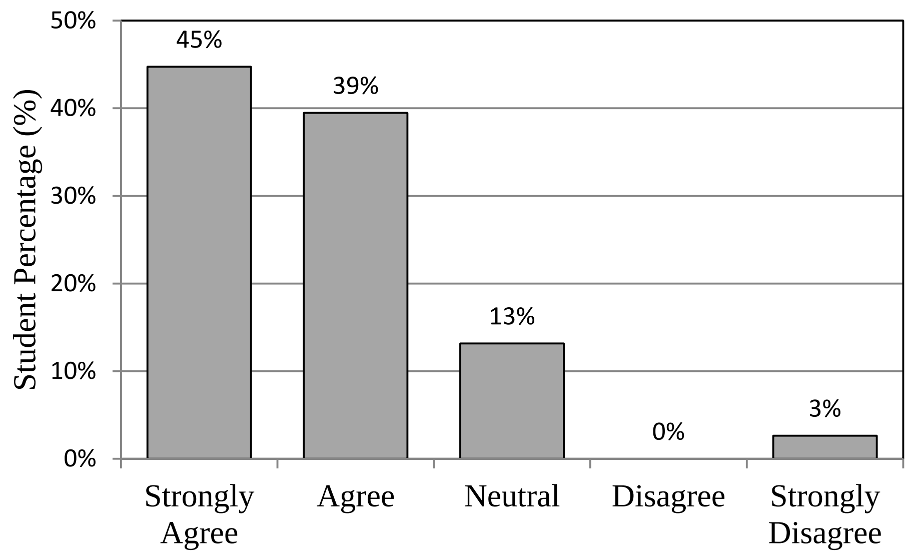

Figure 3. Percent of students that identified active learning activities as a factor that helped them understand the material better or improve their communication and troubleshooting skills (n=38)

Discussion and Future Work

Our results show that introduction of active learning activities, specifically collaborative learning and peer-teaching, significantly increases the average course grades of students in the sophomore-level Systems Physiology laboratory module, as can be seen when comparing the average results of the lab assignments from 2011 and 2013 ($p<0.01$). Content knowledge, measured using the end of the semester test, was also significantly improved for students that participated in active learning when compared to the students that learned the material in a conventional way without participating in the peer-leader sessions ($p<0.01$). These results highlight the importance of active learning techniques not only when teaching lecture courses, but also in the laboratory setting.

Although communication skills were not directly evaluated in this work, previous research suggests that learning by teaching approaches can lead to improvements in oral and written communication skills[5, 13]. In the future, students can be surveyed at the end of the semester to identify if the short lecture presented at the beginning of the course or the one-on-one peer teaching during the lab session contributed to their communication skills. Additionally, the modified in-lab protocols will be used in future years to develop better laboratory manuals and supplement the in-lab activities for upcoming students.

Implementation of the active learning techniques described above considerably improved the quality of BIOE 320 by helping the students gain a more in-depth understanding of the material. The changes described above can be implemented in most laboratory courses and, although they do require the instructor to invest extra time and work during the semester, they do not have any financial cost associated with them. In addition to the regular time spent preparing and teaching this course in 2011, the instructor spent during 2013 approximately 4 extra hours/week (similarly to adding one extra lab section) teaching the peer-sessions, plus the time necessary to grade oral presentations and the modified in-lab protocols turned in by the students.

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