Voluntary participation in an active learning exercise leads to a better understanding of physiology

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Carvalho H, West CA. Voluntary participation in an active learning exercise leads to a better understanding of physiology. Adv Physiol Educ 35: 53–58, 2011; doi:10.1152/advan.00011.2010.—Students learn best when they are focused and thinking about the subject at hand. To teach physiology, we must offer opportunities for students to actively participate in class. This approach aids in focusing their attention on the topic and thus generating genuine interest in the mechanisms involved. This study was conducted to determine if offering voluntary active learning exercises would improve student understanding and application of the material covered. To compare performance, an anonymous cardiorespiratory evaluation was distributed to two groups of students during the fall (control, n = 168) and spring (treatment, n = 176) semesters. Students in both groups were taught by traditional methods, and students in the treatment group had the option to voluntarily participate in two additional active learning exercises: 1) a small group discussion, where students discuss a physiology topic with their Teaching Assistant before running BIOPAC software for the laboratory exercise and 2) a free response question, where students anonymously responded to one short essay question after the laboratory exercise. In these formative assessments, students received feedback about their present state of learning from the discussion with their peers and also from the instructor comments regarding perceived misconceptions. As a result of the participation in these activities, students in the treatment group had a better overall performance χ² (degree of freedom = 1) = 31.2, P < 0.001 on the evaluation (treatment group: 62% of responses correct and control group: 49%) with an observed difference of 13% (95% confidence interval: 8, 17). In conclusion, this study presents sufficient evidence that when the opportunity presents itself, students become active participants in the learning process, which translates into an improvement in their understanding and application of physiological concepts.

A STUDENT IS AS KNOWLEDGEABLE as the training they receive. Such a statement puts a lot of responsibility on teachers/instructors committed to the students’ learning and success. Most educators agree that students do not perform as expected in a classroom setting has yet to be found. Certainly, if the focus of the teaching effort is to promote learning, we should use formative assessment and emphasize feedback as way to inform the learners of their present state of learning.

Particularly in physiology, one important fallacy that needs to be addressed among students is the notion that physiology is a difficult discipline that involves the memorization of names (19). According to Feder (5), “Physiology is the branch dedicated to proliferation of terminology.” When the length of physiology textbooks is analyzed, it is easy to recognize students’ frustrations and why they feel overwhelmed by the excess of content covered by each topic (13).

Many times the instructor uses different equations to talk about the same principle. In Feder’s (5) Fig. 2, there are four different equations for electrical current (Ohm’s law), molecular diffusion (Fick’s law), heat transfer (Newton’s law), and bulk fluid flow (Darcy’s law), when in fact they all could be simplified as a description of flux or exchange among compartments within organisms or between organisms and their environment.

To cover such complex material, some teachers/instructors tend to reinforce the importance of memorization as the ultimate way to learn, when in fact memorization is only the beginning of the learning process and certainly not the end of it. Unfortunately, many students use memorization to pass an exam without learning the material (11). To lessen this problem, teachers spend a great deal of time preparing lessons that are simple and to the point. At face value this seems to be a great approach; however, many students blindly accept what is being taught and are not motivated to think critically about the material being presented. As a result, students miss out on the opportunity to learn and appreciate the thought processes involved when we prepare to teach.

If students are expected to master a large amount of material in a semester, efficient teaching methods must be developed to foster an environment that encourages learning. It is essential to incorporate student involvement, namely, active learning, into traditional teaching, which ultimately stimulates students intellectually and promotes better learning (23). The instructional system (including the formative assessment and feedback) is to facilitate students’ awareness of their own process of learning while the teaching occurs.

The practical part of the course presents an ideal opportunity to facilitate learning and application of knowledge acquired in
How We Teach

We hypothesized that a student’s ability to explain physiological phenomena can improve if they participate in an active-learning classroom.

**MATERIALS AND METHODS**

This study was conducted using two sets of undergraduate students enrolled in the Health Sciences Program at Virginia Commonwealth University. The control group had 168 students composed of 2 sections with 84 students each from fall 2008; the treatment group had 176 students composed of 2 sections with 88 students each from spring 2009. Both the control and treatment groups had the same instructors, lecture format, and laboratory protocol. The students’ performance was compared before (control) and after (treatment) the introduction of active learning exercises in the program.

Both groups attended a traditional physiology laboratory, and an end of course cardiorespiratory evaluation was distributed to students from both groups at the end of the semester, which was used to compare group performance. Members of the treatment group also had the opportunity to actively participate in two additional voluntary activities: 1) a small group discussion and 2) a free response question. These activities were voluntary; students were verbally stimulated to participate, but they did not receive any bonus for participating or punishment if they did not. Table 1 shows the sequence of activities offered for both groups.

**Traditional Learning**

The traditional physiology laboratory began with a 15-min lecture given by one of the eight graduate students working as Teaching Assistants (TAs). The short lecture was based on one of the topics covered in the BIOPAC (BioPac Systems, Goleta, CA) laboratory manual (21). In the sequence, students would follow the step-by-step instructions in the manual to perform a physiology exercise. Student understanding of the concepts covered was evaluated by weekly laboratory reports and multiple-choice quizzes given every other session. The laboratory reports consisted of a series of short-answer questions found at the end of the laboratory exercise in the laboratory manual, and the quizzes were prepared by the course director.

A voluntary and anonymous cardiorespiratory evaluation (Table 2) was given to both the control and treatment groups on the last day of the course to evaluate the effectiveness of the active learning strategy.

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### Table 1. Sequence of daily activities offered to each group in the study

<table>
<thead>
<tr>
<th>Activity</th>
<th>Control Group</th>
<th>Treatment Group</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quiz</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Lecture (15 min)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Small group discussion (~8 min)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Laboratory exercise (30-60 min)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Free response question (~3 min)</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Laboratory report (homework)</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

序列为每天活动提供的每个小组的活动。

<table>
<thead>
<tr>
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<tr>
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<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

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### Table 2. Cardiorespiratory evaluation passed to all groups of students

Please Choose One Answer From the Options Presented

1. You just finished playing a soccer game. The exercise was very rigorous, and you note that your heart rate increased. What do you believe would happen with the strength of your heart beat? Please give a short explanation including the action of the nervous system.
   A. Increase*
   B. Decrease
   C. Remain unchanged

2. You arrived late for the physiology exam and found out that it will take place on the sixth floor. Because the line for the elevator was too long, you decided to run up the stairs. As you arrived to class, you could barely focus because of the change in your respiration pattern. What happened with the depth (increase*, decrease, unchanged) and rate (increase*, decrease, unchanged) of your respiration? Explain your choice including the role of chemoreceptors in your answer.
   A. Increase*
   B. Decrease
   C. Remain unchanged

3. When the metabolism of the body increases, ventilation will (increase*, decrease, stay the same). Circle one.

4. A large vein in the leg is cut during an accident, and the individual loses 2 liters of blood. The pressure in her veins will (increase, decrease*, stay the same). Circle one.

5. The ventricle fills only when:
   A. The atrium contracts
   B. The pressure in the ventricle is less than the pressure in the atrium*
   C. The papillary muscles contract and open the atriocentric valve

6. When the heart beats, the right ventricles pump (the same*, more, less) volume of blood than the left ventricles. Circle one.

7. If all of the nerves innervating the heart are cut, will the heart continue* or stop beating? Why?

8. The left ventricle contracts NOW. The right ventricle contracts (before, after, at the same time*). Choose one.

9. The blood flow through the pulmonary circulation is (the same as*, greater than, less than) the blood flow through the systemic circulation. Circle one.

Questions were adapted from Ref. 14. *Correct answer(s).
This study was approved by the Virginia Commonwealth University Institutional Review Board as an exempt experiment since the evaluation was anonymous and voluntary. It contained seven multiple-choice questions and three short-answer questions. The questions selected were based on physiological parameters from everyday activities or information from the lecture, and they were adapted from the report of Michael and coworkers (14). Students were instructed that they should respond individually using their own words and avoid “guessing” or leaving the question blank if they were not confident that their response was correct.

Active Learning Approach

The treatment group was offered a couple of extra activities: 1) a small group discussion and 2) a free response question. These voluntary activities were offered as a complement to the traditional lecture and laboratory exercise.

Small group discussion. In the treatment group before the start of the semester, the eight TAs were assigned one or two groups of six students each. Before the beginning of each session, the instructor and TAs reviewed the question, and the TAs were instructed to stimulate the students to talk and not to give the answer. Immediately after each lecture, the TAs initiated the small group discussions for their assigned students. The group discussions were drawn from the three physiology questions previously distributed by the instructor and were derived from the theme for the week’s laboratory. The TAs were closed monitored by the instructor, who circulated in the classroom to prevent TAs from giving the answers but to encourage the students to participate and provide a response themselves. After the discussion, the groups would begin the laboratory exercise following instructions from the BIOPAC laboratory manual.

Free response question. At the end of each laboratory session, students from the treatment group were invited to respond to a voluntary and anonymous free response question related to that day’s activity. They could respond individually or as a group and could use any didactic material available, as long as they did not copy the words from the textbooks. The goal was to help students develop the ability to express their knowledge in writing.

In this formative assessment, students compared their knowledge with their peers during discussion and heard feedback from the teacher about correct answers and misconceptions. This activity was an additional component of the active learning exercise, and the goal of such a task was twofold: it created an opportunity for the students to 1) synthesize material from lecture, discussion, and the laboratory manual and 2) develop writing skills without the pressure of being graded. The following is an example of such a question: “Does exercise affect systolic pressure the same way it affects diastolic pressure? Please explain using your own words.”

Statistical Analysis

Responses to the evaluation were categorized as either correct or incorrect, and blank responses were ignored in the data analysis. Since the evaluation was voluntary and not graded, students could decide whether or not they wanted to respond a particular question regardless of whether they knew the response.

The total number of correct responses from the evaluation was calculated separately for multiple-choice and discussion-type questions for both the control and treatment groups.

There were no added costs for the implementation of the activities (for the treatment group). The TAs were present regardless of experimental treatment, and the only change was to use some of the class time for discussion. The laboratory/class finished when the students were done with the activity, which rarely occupied the whole time designed for the class. The overall effect size was 0.179 (or 18%); the effect size for the discussion question was 0.486 and for the multiple-choice question was 0.117, which shows that the major benefit was for the discussion question.

A χ²-test was used to assess the independence of treatment and performance on the evaluation. Furthermore, a 95% confidence interval (see Table 3) was generated for the difference. The null hypothesis was rejected at P < 0.05.

RESULTS

Cardiorespiratory Evaluation

Student participation in the evaluation was assessed by the total number of responses obtained from both groups (Table 4). The apparent difference response rate of the two groups was not clear. Possibly students in the control group were willing to participate in responding to the end of course evaluation because it was the first time that they were asked to do voluntary “extra work.” Students in the treatment group had participated many times before, and some of them might have not felt obligated to do voluntary extra work once more. Overall, 65% of the control group responded and 51% of the treatment group responded. For multiple-choice questions, 75% of the control group responded, whereas 58% of the treatment group responded. For the discussion question, 42% of the control group responded, whereas 35% of the treatment group responded.

The χ²-test showed the dependence between treatment and performance on the evaluation. We observed a significant

### Table 3. Summary statistics of differences between groups

<table>
<thead>
<tr>
<th></th>
<th>Difference, %</th>
<th>SE, %</th>
<th>95% Confidence Interval</th>
<th>P Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Multiple choice</td>
<td>8</td>
<td>2.46</td>
<td>3, 12</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Discussion</td>
<td>32</td>
<td>4.66</td>
<td>22, 41</td>
<td>&lt;0.001</td>
</tr>
<tr>
<td>Overall</td>
<td>13</td>
<td>2.22</td>
<td>8, 17</td>
<td>&lt;0.001</td>
</tr>
</tbody>
</table>

### Table 4. Summary of the end of course evaluation

<table>
<thead>
<tr>
<th></th>
<th>Number of Students</th>
<th>Number of Questions</th>
<th>Number of Possible Responses</th>
<th>Actual Responses Number %</th>
<th>Correct Responses Number %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Overall</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control group</td>
<td>168</td>
<td>10</td>
<td>1,680</td>
<td>1,089 65</td>
<td>538 49</td>
</tr>
<tr>
<td>Treatment group</td>
<td>176</td>
<td>10</td>
<td>1,760</td>
<td>896 51</td>
<td>555 62</td>
</tr>
<tr>
<td>Multiple choice</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control group</td>
<td>168</td>
<td>7</td>
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<td>876 75</td>
<td>490 56</td>
</tr>
<tr>
<td>Treatment group</td>
<td>176</td>
<td>7</td>
<td>1,232</td>
<td>713 58</td>
<td>456 64</td>
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<tr>
<td>Discussion</td>
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<td></td>
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</tr>
<tr>
<td>Control group</td>
<td>168</td>
<td>3</td>
<td>504</td>
<td>213 42</td>
<td>48 23</td>
</tr>
<tr>
<td>Treatment group</td>
<td>176</td>
<td>3</td>
<td>528</td>
<td>183 35</td>
<td>99 54</td>
</tr>
</tbody>
</table>
increase in the percentage of correct responses for the treatment group in all question types, as shown in Fig. 1. Overall, 49% of the control group gave correct responses, whereas 62% of the treatment group did \( \chi^2 \) (degree of freedom \( df = 1 \) = 32, \( P < 0.001 \)) with an observed difference of 13% (95% confidence interval: 8, 17). When we analyzed separately by question type, 56% of the control group responded correctly for multiple-choice questions, whereas 64% of the treatment group did \( \chi^2 \) (df = 1) = 10.5, \( P < 0.01 \). For the discussion questions, 23% of the control group and 54% of the treatment group responded correctly \( \chi^2 \) (df = 1) = 70.9, \( P < 0.001 \); Table 4.

**Small Group Discussion, Free Response Question, Misconceptions, and Feedback**

Instructors and TAs observed more engagement among the students, as a larger number of students participated in the small group discussion and the duration of this activity increased. Participation in the free response question also increased throughout the semester, even though there were no attempts to quantify this activity since the responses could be individual or by groups. These free response questions revealed misconceptions that were discussed with the entire class. Table 5 shows some of the misconceptions observed.

**DISCUSSION**

This study indicates that when active learning exercises are offered and students have the opportunity to participate in them, their performance improves, as observed by the students in the treatment group with a greater percentage of correct answers compared with the control group that received only traditional teaching.

The success of this study was largely due to the TAs’ participation in student engagement. Over the course of the semester, students became increasingly involved in both the small group discussions and free response questions, indicating that heightened interest and motivation are more important in learning than intelligence. Furthermore, other studies have shown that TA participation in large classroom settings has a positive impact (17), since peer instruction enhances meaningful learning (2), thereby improving a student’s ability to transfer information from one situation to another.

**Small Group Discussion**

To permit students active participation in a large classroom setting, we divided the class into smaller groups with 6–7 students/TA, making the classes “feel smaller” and allowing peer-to-peer instruction as well as team work.

The discussion of physiology between undergraduate and graduate students during the small group discussion period was aimed to explore the students’ competence in thinking and verbalizing their ideas in an attempt to aid their understanding and ability to explain how a particular physiological phenomenon occurs. Small group discussion accomplishes several things: it improves communication skills (18), promotes deeper understanding of physiology among the graduate students (TAs), and facilitates the discussion of physiological concepts among the undergraduates, thereby leading to critical thinking in both groups of students (graduates and undergraduates).

**Free Response Question**

The goal of this formative assessment was to stimulate students to write and test their own learning. Both the teacher and students benefited when the content and format of what was being taught were adapted based on student performance. Students were informed that the purpose was to enhance learning, not to allocate grades.

Without fear of being penalized by grades, students could freely express themselves and their understanding about how things work and the physiological mechanisms involved. A previous study (9) has shown that when students express ideas using their own words, the learning process occurs. As ex-

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**Table 5. Examples of misconceptions observed from the free response question**

<table>
<thead>
<tr>
<th>Misconception</th>
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<tbody>
<tr>
<td>Some students understand that exercise increases the depth of respiration, but they do not make any connection, or don’t know how to explain, the alterations on respiratory volume and capacities.</td>
</tr>
<tr>
<td>Some students think that total lung volume increases after exercise, showing the wrong concept that the lung could expand more than its size under resting conditions.</td>
</tr>
</tbody>
</table>

**Other observations from the daily survey**

Students mixed the role of \( O_2 \) and \( CO_2 \) as they explained the control of respiration. Almost nobody mentioned tidal volume, and they did not really understand what respiratory dead space is.

A student thinks that during exercise blood flow does NOT go to the lung.

During hyperventilation, a person would \( CO_2 \) instead of \( O_2 \) and the slow breath takes out the \( O_2 \).

\( CO_2 \) in the lungs (not in the blood or cerebral fluid) triggers the respiration pattern.

Systolic and diastolic pressure change together after exercise.

During systolic pressure, you are inhaling.

Temperature affects blood velocity by itself, not related to vessel diameter.
pected, most students were resistant to this new approach to learning and initially were apprehensive about participating in the activity. At first, it was common for students to ask and/or wait for TA/instructor to provide an explanation and ultimately provide the answer to the question. This was clearly illustrated when one student stated “I don’t mind the method, as long someone tells me the right answers.”

There were varied reactions to the free response question. Some students responded by stating a biological concept that they learned in a prior course but were unable to connect the information taught with the question. Other responses demonstrated superficial knowledge similar to the response one would expect from a layperson. Occasionally the free response question was responded to by a group of students, a desirable outcome since learning often occurs from the discussion within a group. It was observed that critical thinking most often occurred when students would use the free response question to ask each other questions or to confirm/confront their ideas about the physiological mechanism. Many times the students used this activity as a tool to anonymously communicate theories or concepts of which they were unsure and would like to discuss in upcoming sessions. Feedback was especially useful because students were “primed” with the question early and it encouraged them to immediately think about where they went wrong in their understanding of the topic (4), and over time student participation increased.

Passive Versus Active Learning

It is common knowledge that students do not learn by sitting and passively absorbing everything already digested by the instructor. Even in a practical laboratory there is a tendency for some students to become passive and copy data from colleagues. Following the steps in a laboratory manual does not promote critical thinking, but when someone talks about what they are learning, writes about it, relates it to past experiences, and applies it to their daily lives (8), long-term learning takes place. By verbalizing their understanding of a topic, a person is forced to make their explanation more concrete and specific, thereby promoting long-term memory.

For the students that participated in the voluntary activities, the feedback was a great learning tool. As they were previously “primed” during the discussion or as they wrote about a specific topic and heard the feedback that was delivery to the whole group, they improved their understanding as they knew how they were progressing during the semester.

These instruments were of great value to the students in understanding physiology and for instructors to know more about student and TA behavior. TAs exhibited a variety of behaviors. Some TAs were more engaging and even searched for ways to improve the discussion by including interesting case studies found on the internet. However, there were some TAs who became popular among the students by giving direct responses upon request without stimulating the students to think for themselves. The ultimate success of the project depended on everyone’s willingness to promote active learning. This could not be something that just came from the top; everyone, especially the TAs, had to be willing to participate.

An interesting observation was noted when students cheated. Since the free response questions were not graded, there was no way to associate who responded to the person or group that submitted the answer. Although there should have been no reason to cheat, there were a few times when the same wrong responses, sometimes with the same wording, were turned in. These observations were shared in class during the feedback session.

Where Do Misconceptions Come From?

The free response question was an especially useful tool to identify misconceptions among students (see Table 5). Some misconceptions were probably the perpetuation of faulty understanding acquired from prior courses or based on observations made in daily life. During this study, special attention was given to identify any misconceptions observed during the laboratory activity. An example of a misconception that arose after the laboratory activity happened when students used the ECG to measure heart rate before and during a deep inhalation and exhalation. From the free response question collected after that exercise, it was found that some students were of the belief that the respiratory cycle “controls” the heart rate because they observed the respiratory pattern affecting the frequency of cardiac contraction. This matter was immediately addressed during the feedback at the beginning of the next session, where the instructor explained the influence of baroreceptors and the central nervous system in controlling the respiratory and heart rate as well as changes in venous return during deep inspiration. If we cannot address these misconceptions in a timely manner and give prompt feedback to the students while learning is taking place, erroneous ideas like this would be perpetuated. The most disheartening part of this situation is the fact that these misunderstandings come from the place where students are supposed to learn: the classroom.

Misconceptions may arise from different sources. In a formal education setting, the prevalence of misconceptions has been described in elementary school teachers regarding blood circulation (20). Also, as found in many textbooks, some comparisons can lead to the wrong interpretation of facts, e.g., the comparison of alveoli with grapes or independent balloons (22) when, in fact, the alveoli share a common wall.

In this study, every effort was made to minimize the amount of misconceptions, because once they are assimilated they are very difficult to eliminate. Morton (16) showed that only one of nine misconceptions were corrected in a study regarding exercise physiology and biochemistry.

Physiology is considered difficult, mostly because of the large number of names and complex concepts needed to be mastered in a short period of time. Learning and memorization are not the same (12). Part of the problem with the traditional style of teaching resides in the fact that knowledge in science continues to expand and instructors would like to present the most up to date information to their students. To understand physiology, a sound background in physics and chemistry is vital. Elementary physics in high school is receiving less attention (25), probably due to the advent of new areas, such as molecular biology. The attempt to incorporate more and new information, in all levels of education, results in less time being dedicated to teaching basic concepts in the sciences.

There are many alternative ways to teach, including in-class reviews, games in physiology (26), the construction of concept maps (6, 15), or the use of image-based manipulatives (10).
The use of multiple tools for teaching (24) appears to improve learning.

Our goal is to develop in students life-long learning habits and to help them learn physiological concepts by understanding instead of memorizing. In conclusion, when active learning opportunities are offered, students become engaged, resulting in an improvement in their learning experience. Furthermore, the teaching style used in this study facilitates a student’s ability to explain physiology, and we hope that they have learned, retained, and are able to apply the information presented in different situations. It is clear that when efforts are made to implement student-centered learning that students respond positively, as reflected by the following comment from one student: “Thank you for helping me to think.”

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DISCLOSURES

No conflicts of interest, financial or otherwise, are declared by the author(s).

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