Understanding data collection in the modern physiology laboratory

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Advan in Physiol Edu 33:78-79, 2009. ;
doi: 10.1152/advan.90174.2008

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Stasinos Stavrianeas

Department of Exercise Science, Willamette University, Salem, Oregon

IN A RECENT INFLUENTIAL REPORT by the National Research Council (2), the role of the laboratory was introduced as follows:

> Science courses and the laboratories associated with them should cultivate the ability of students to think independently. They should provide students with exposure to realistic scientific questions and highlight those aspects that are inherently interdisciplinary. They can also provide opportunities for students to learn to work cooperatively in groups.

Our role as educators requires that we facilitate the students' journey toward independent learning in accordance with current standards in science pedagogy, but we must also remain alert as to what students actually learn and how they learn it. The incorporation of digital data-acquisition systems into the human physiology curriculum has provided wonderful opportunities for student-centered investigative activities in the laboratory. With funding from the National Science Foundation (Division of Undergraduate Education Grant 0309546), we equipped our laboratory with eight complete data-acquisition systems (Biopac) to accommodate several small groups of students in the Human Physiology course working together (the class is capped at 16 students). The equipment was easy to set up and has high reliability, two elements that facilitate student learning by removing apprehension regarding their ability to collect and analyze data of high quality. Through these experiences, students gain confidence and are certainly more accepting of the possibility for independent research and discovery.

In the experience of this instructor, these systems have successfully transformed the physiology laboratory. Students are now more willing than ever to work cooperatively in designing and carrying out their experiments. In accordance with modern science pedagogy guidelines, they collect, analyze, and present their own data while being careful to interpret their findings using established physiological principles. However, it has become apparent that students seldom gain an understanding of the *process* by which data are collected. In addition, more often than not, students could not interpret the values on their screen in real time. In other words, they accepted the data generated by these devices at face value without ever questioning the accuracy or application of these values. This realization, unexpected and unpleasant as it may have been, should not have been surprising as, up to that point, there was no place in our curriculum to discuss issues of instrument reliability and validity. The only prerequisite for this course is a semester-long course in Human Anatomy, where the emphasis is on dissection and identification of structure and form. The brief exercise described below is administered during the fifth week of our semester-long, sophomore-level Human Physiology course. By that time, students have become familiar with the data-acquisition systems and have even performed experiments of their own design using the EMG module (which includes a basic calibration). For a complete description of all laboratory activities and objectives, the reader is referred to the course website at www.willamette.edu/~stas/physiology.

The main objective of this laboratory is to study the process of muscle contraction and understand the characteristics of excitation-contraction coupling using the established frog gastrocnemius muscle stimulation model. This objective is explicitly stated on the course website and repeated before the start of the lab. A secondary objective, which is not shared with the students ahead of time, is to help them understand the importance of properly calibrating their scientific instruments, assess the accuracy of their data, and gain confidence in their experimental data and conclusions.

Before the frog dissection, students are warned to always examine all information and data with a critical eye. They are specifically told to ". . . *never* take anything for granted . . ." as they proceed through the experiment. Students are asked to prepare the data collection station, namely, the digital unit (Biopac) and associated peripherals (i.e., force transducer). To test their experimental setup, each group is instructed to gently pull on the transducer (simulating a muscle contraction) and verify that a force reading registers on their computer screen. Students are then asked to measure how many grams of force they generated using the software analysis function and record their answers on the whiteboard. When all the groups have posted all their values, the instructor asks: "How do you know the values are accurate?" After being admonished for the inevitable ". . . because the computer said so . . .," students are challenged to identify some process by which they can confirm the accuracy of their measurement, and again they are reminded to question all results. At this point, the instructor completely removes himself from the laboratory, forcing students to search for answers through peer-to-peer collaborations. The instructor's return ~10 min later inevitably coincides with at least one group identifying a proposed solution (or stumbling onto it, as the case may be), namely, the generation of a standard curve. The students ask for and receive a set of premarked weights to be used for the task. What the students do not know is that the instructor has deliberately marked all the weights at values different from their actual weight. For example, the 5-, 10-, 15-, and 20-g weights are marked as 4.5, 9, 13.5, and 18 g, respectively. All sets of weights are identically marked, so all students obtain similar results.

The students promptly and diligently generate a standard curve, almost always with very high correlation coefficients between the weights given to them and the values measured by the Biopac systems; in the most recent laboratory, the values ranged from $0.997 < r < 0.999$. The difficulty, of course, is that when students are asked to confirm the accuracy of the values, there are (obviously!) disagreements; students are then challenged to identify the problem with their measurements. It

Address for reprint requests and other correspondence: S. Stavrianeas, Dept. of Exercise Science, Willamette Univ., 900 State St., Salem, OR 97301 (e-mail: stas@willamette.edu).

is of course necessary to phrase the instructions in a way that does not reveal the reason behind the error, by saying something like ". . . review your procedures and verify that you did everything correctly." It quickly becomes apparent to the students that their instruments are very reliable (i.e., they obtain the same results) but apparently not valid for the task at hand. Students are again asked to devise a strategy to deal with this problem, and the instructor finds an excuse to again remove himself from the room, announcing that he will be working in an adjoining prep room. Rough records over the past 5 years have indicated that students usually require ~10–12 min before they ask to weigh the weights on a calibrated scale. Naturally, as soon as they do so, the source of the "error" is revealed, and the frog dissection can actually proceed as planned.

It must be stated that this exercise usually lasts ~1 h and never fails to elicit strong feelings on the part of the students. The words "tricky" and "devious" have been used in describing this laboratory exercise immediately after the facts become known. Yet, these feelings quickly subside because of three reasons. First, presenting students with less than complete information is a tactic often used in the lecture portion of the course. In accordance with the guidelines articulated in the Project 2061 report (1), students are often challenged to think how any particular mechanism or instrument would work and why. Even if their hypotheses are wrong, these exercises serve as learning tools, showing students how to assess the problem before them, establish a logical progression of arguments based on data, facts, and previous knowledge, and present their case to the class. Thus, students are hardly surprised by this laboratory activity. Second, students are given access to peer-reviewed articles published in scientific/academic journals, where the issue of equipment calibration is mandatory and always addressed. Thus, the students easily identify the importance of equipment calibration and, by extension, the value of this exercise. Third, given the instructor's strong and repeated warnings throughout the laboratory, students always recognize that they were simply presented with a scientific problem and appreciate the educational value of the experience. The small class size also facilitates such discussions and more informal exchanges between the instructor and students, where these issues are presented and analyzed, so the relationship between the instructor and the students is never threatened. These followup exchanges have resulted in minor modifications of the activity over the years. For example, the idea of stamping the weights with the wrong values belonged to a former student.

As a matter of fact, discussions with the students in subsequent science courses have revealed their appreciation for this activity, in that it exposed them to the necessary critical-thinking skills and prepared them well for similar activities (see Ref. 3). Many students have also connected this exercise on equipment accuracy with the theoretical discussions about reliability and validity in experimental measurements in their Research Design courses. In summary, students view this exercise in a positive light, as one of the experiences that shaped their undergraduate experience in the sciences.

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