Project labs in physiology

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Woodhull-McNeal, Ann P. Project labs in physiology. Am. J. Physiol. 263 (Adv. Physiol. Educ. 8): S29–S32, 1992.—Projects in which students design and carry out their own experiments can be a basis for physiology laboratories. A sequence of such projects is described and evaluated informally. It is argued that these inquiry-oriented project labs serve to motivate and teach students important concepts and attitudes about the nature of science and their ability to participate actively in it. Although physiology laboratories are a standard part of physiology courses, teachers are not always clear about the purposes of these activities. At least three categories of purpose seem important: the conceptual, the motivational, and the technical. As laboratories are being replaced in some cases by videodisc or computer simulations, it is important to see which purposes can be served by simulations and which cannot. Project-based laboratories, even more than standard laboratories, can serve the technical, motivational, and conceptual purposes for our laboratory teaching.

WHAT ARE THE PURPOSES OF LABORATORIES IN PHYSIOLOGY COURSES? I would argue that we have a wide range of goals in mind when we teach labs and that we can better understand the current debate about the use of video simulations of labs when we know why we do what we do. I also want to make a case for not only continuing our "wet labs" but for greatly expanding and strengthening their most challenging aspect: the chance for students to do original research on a small scale. Some of our common purposes are listed in Table 1.

It is my view that physiology laboratories can and should teach on many different levels simultaneously. Because the designation "laboratory" can be applied to a range of activities from demonstrations to student-designed experiments, let me clarify that I shall mean laboratory exercises carried out by the students, using live materials or real objects. Video or computer simulations likewise vary in quality, from completely passive slide shows to complex simulations of labs, in which students are asked to interpret data similar to that obtained from real laboratory exercises. When the purposes outlined in Table 1 are looked at, it seems to me that the best simulations can accomplish most of the purposes stated under the conceptual section but that even these simulations have less promise in the motivational and technical areas. Poorer simulations fail most conspicuously in the areas of hypothesis testing, learning about scientific inference, and stimulating inquiry.

MOTIVATION

Two recent articles in Advances in Physiology Education presented very different models of laboratory teaching, based on different assumptions. On the one hand, Randall and Burkeholder (9) described laboratories in which students became very excited by being able to do experiments with videodisc labs in which experiments are simulated by computer, stating that students who did the nonexperimental labs performed just as well on tests of their knowledge. I strongly believe, along with Winders and Yates (11) and Dawson et al. (4), that live laboratories provide something quite different from review exercises. [I differ from Dawson et al. (4) in my belief that stimulating and genuinely experimental labs can be done without the use of live animals.]

Because I am very fond of teaching laboratory physiology, these articles stimulated me to sit down and describe my own lab sequence, developed with colleagues over the years. The sequence is designed to foster students' skills in designing as well as carrying out laboratory investigations.

Laboratories in which students use live materials, especially those that allow students to design their own experiments, lead to learning that is qualitatively different from that gained through texts, demonstrations, and, in most cases, videodisc. Some of the unique opportunities offered by such labs are as follows.

1) Students make mistakes, and mistakes are instructional. When they do things wrong or sloppily, their mistakes have consequences that they can see plainly, so they must learn care and technique. Also, they have to figure out just what they did wrong, and troubleshooting is a technique and mind-set important in medicine and life as well as in research.

2) Hands-on science teaches the texture, both literally and figuratively, of things. The concrete experiences may help students to remember concepts long-term, not just until the next test. Learning only from the book without concrete referents is like reading Shakespeare only silently: videodisc and demonstration are more like seeing a performance, whereas designing and carrying out experiments is being in the performance.

3) Laboratories can be motivational if they have a true experimental quality and are not just highly controlled experiences demonstrating particular phenomena. Students get excited about formulating questions and trying out their own ideas; becoming actively involved, they perform much better.

4) Through designing and carrying out their own experiments, students realize that they can use the scientific process to answer their own questions. They need not be passive learners. They also can learn whether they want to become scientists.

5) Students, who are the next generation of decision makers, learn the actual qualities of science, including its uncertainties and limitations. Such knowledge can inform their input into societal decisions about the uses of science.

I contend that these reasons should lead us not only to retain real labs but to fashion our labs to be more truly experimental.
Table 1. Some common goals of physiology labs

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<th>Conceptual</th>
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<tr>
<td>Reinforcing facts learned in lectures and texts*</td>
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<tr>
<td>Mastering higher level concepts such as models of systems*</td>
</tr>
<tr>
<td>Inferring scientific principles from data*</td>
</tr>
<tr>
<td>Formulating scientific questions*</td>
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<tr>
<td>Using controls*</td>
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<tr>
<td>Designing experiments</td>
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<table>
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<tr>
<th>Motivational</th>
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<tr>
<td>Stimulating curiosity and motivating exploration*</td>
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<tr>
<td>Experiencing working and thinking as scientists</td>
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<tr>
<td>Experiencing more autonomy and initiative in relation to learning</td>
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<tr>
<td>Gaining (literally) a feeling of organisms</td>
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<tr>
<td>Learning care and responsibility (learning that actions have consequences)</td>
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<td>Learning from mistakes and improving on designs</td>
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Technical

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<th>Learning data analysis skills, including statistics and use of computers*</th>
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<tr>
<td>Learning skills of hypothesis testing*</td>
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<td>Enhancing quantitative skills*</td>
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<tr>
<td>Communicating effectively about science</td>
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<tr>
<td>Learning to collaborate and share ideas</td>
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<tr>
<td>Learning laboratory techniques and manipulative skills</td>
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* "Wet labs" can contribute to all of these goals. * Goals to which good simulations can probably contribute.

OPPORTUNITY

I want to make a case for project-based laboratories which, rather than simply providing a parade of techniques and concepts, encourage students to design experiments testing their own ideas within the framework of techniques they learn. I shall use as examples the laboratories we have developed over the past 15 years as part of a physiology course at Hampshire College. This intermediate-level course serves 10–25 students at a time. It is a fairly conventional physiology course, using as a text either Animal Physiology: Mechanisms and Adaptations by Eckert et al. (5) or Human Physiology: The Mechanisms of Body Function by Vander et al. (10). Ambrose and Ambrose’s Handbook of Biological Investigation (1) is sometimes assigned as a supplemental text because it gives techniques for statistical data analysis and for writing laboratory reports in the form of scientific papers. Students also read primary and secondary literature on some of the topics of the course.

To allow students time to develop ideas and techniques, we have reduced the number of different exercises to approximately four per semester, 3–4 wk/lab (Table 2). Each of the projects centers on using a different technique and different body system. Four techniques have formed the core of a one-semester physiology course: electrophysiology, biochemical assay, noninvasive measurements on humans, and dissection. We have also tried doing a sequence of more conventional 1-wk labs followed by a longer project. However, we have found that it is difficult to manage switching late in the semester to suddenly requiring student initiative because students are not prepared. I prefer to emphasize the importance of experimentation by doing it consistently, teaching students to look constantly for the experimental opportunity.

Although live animal preparations are important in physiology (4), they are not the only way of introducing students to experimentation. Noninvasive techniques used on their own bodies can provide students with vital experiences. I have accepted the constraints of not working with mammalian preparations or species that are endangered by being overused by biologists. Therefore, I use no rats, frogs, or turtles.

METHODS

For each of the project labs (Table 2), students are first introduced to the new technique, which they practice with a set exercise during the first week. They then design their own experiments within rather clear parameters and carry out the experiments over the next few weeks. Data analysis and interpretation are given time within the lab periods. In the descriptions below, I give a great deal of detail concerning the first project lab (see Electromyography and Experimental Design), to illustrate the structuring of this sort of exercise.

Dissection

Dissection of a fresh fish in teams of two gives students a chance to see, feel, and smell the organ systems. Students are asked to observe each body system in the fish, noting its size, shape, color, and anatomic connections. They are asked to estimate the number of cells in the fish brain. Using fish rather than frogs or rats makes the exercise more challenging for students who have already done such dissections.

Electromyography and Experimental Design

This is an easy technique with which to get quick and gratifying readings, but it can be difficult to obtain clear, consistent results. Hence the electromyography (EMG) project provides good motivation for improving experimental technique.

**Day 1: EMG technique and rationale.** The technique of EMG and its rationale are introduced, as well as a bit of anatomy and biomechanics. Working in groups of four, using themselves as subjects, students choose a muscle and record from it during numerous static exercises to try to find the maximum voluntary contraction. They analyze the data from the strip chart by hand, plot bar graphs, and present these to the class. Each group must devise an experiment to carry out and analyze over the next few weeks. The experiments are devised with these constraints: the activity of one muscle is to be compared under two different conditions; each activity must be repeated 10–12 times (therefore, it must not be too fatiguing); conditions must alternate; the movement must be static or slow (to minimize movement artifacts and problems of variability in speed); and at least

Table 2. Sequence of labs in project-oriented physiology

| 1) Dissection of fish (Tilapia). Orientation to body systems and also to quantitative problems of estimation (1 day). |
| 2) Electromyography on humans and experimental design. Small groups of students carry out original projects within given format. Statistics, experimental design, and use of computers for data acquisition and data analysis are introduced as an integral part of lab (4 days). |
| 3) Blood glucose levels of human subjects. Spectrophotometric technique, standard curve. Using a primary paper to provide ideas for group experiment (3 days). |
| 4) Cardiorespiratory variables measured noninvasively. Many measures ranging from resting heart rate to estimated and actual maximal oxygen uptake. Making sense of a relatively large data set using correlations and other statistical measures (4 days). |
three subjects must be tested under the same experimental conditions.

The reason for these constraints is that the experiment also will introduce the use of the t-test for testing hypotheses. In contrast to the structure of the experimental design, students are encouraged to try anything that suits their fancy for an experimental idea, as long as the results are not too obvious in advance. They have compared the following: different types of abdominal exercises to see which best activates the rectus abdominis; different head positions to test postural activity of the neck muscles; back muscle activity in different sitting positions; different pilates techniques from dance, looking at thigh muscle activity; and relative relaxation of muscles in different stretches from yoga. During the first lab period or before the next week, each group must carry out a pilot run of its experiment and analyze the data by hand.

**Day 2: introduction to statistics and computerized data acquisition.** Each group now has a table of data consisting of 10–12 samples of muscle activity under each of two conditions. The lab begins with a presentation of some theory on distributions, normal curves, and histograms. Working groups make histograms of their data with both conditions in different colors on one graph. They then show the data and draw tentative conclusions from the graphs about whether the muscle activity under one condition was really different from activity under the other condition. Because they have their own raw data, the students are highly motivated to learn the statistical concepts.

During this lab period, they also learn how to use LabTech Notebook (Laboratory Technologies) software on the computer to carry out computerized data acquisition. Most of the data acquisition program is set up already, but they need to change some parameters such as the scale factor. Again, the idea is to use data acquisition to facilitate their experiments. Therefore, the program is set up to sample 2-s segments of activity repeatedly, 10 samples/s, on triggering. The data then have to be averaged within each 2-s trial; students learn to use the Quattro spreadsheet to average the data, or else I provide a program to do so. If the project ideas are fairly simple, lab groups can complete their experiments using data acquisition during lab time. Otherwise, they may sign up for more time during the week to complete their experiments and prepare tables of data before the next week.

**Day 3: data analysis by statistics and graphing.** First, the use of standard deviation and the t-test is introduced, and we calculate one example of a standard deviation by hand. Students then go to the computers and are introduced to a statistical package (Minitab). They read their own group data into Minitab and spend the lab period obtaining and interpreting statistical results (means and SDs, t-test). Students learn to use a graphics package (Quattro or XeroxGraph) to make bar graphs of their overall results and line graphs to look for time trends. In research experiments, data analysis is a large component. Here, students are encouraged to spend time and creative energy on data analysis. For example, some students have seen time trends indicating that subjects were getting tired (increasing amplitude of EMG), although this was not the purpose of the experiment.

**Day 4: presentation of projects and more statistics.** Each group gives a formal presentation of its purposes, methods, and results. The discussion is usually lively and full of ideas for further research. This is also a good time to introduce more statistical concepts such as correlation and regression, which will be used in future labs.

**Blood Glucose**

As in the EMG lab, students are first given clear direction in learning the technique and are then required to design their own experiment. The first lab period is spent learning how to use the spectrophotometer and generating a standard curve for glucose. In groups of three, students also determine blood glucose for one person. All the precautions that are necessary in this age of acquired immune deficiency syndrome (AIDS) are taken (i.e., sharps are disposed of correctly, and gloves are used even in handling diluted blood). Before the first lab period, students read a recent primary article on blood glucose changes after ingestion of sugar or starch (e.g., Ref. 3 or 8), and they collectively devise one project that they then carry out over the next two weeks. This has involved feeding subjects one food at the beginning of the lab on the first week and a different, isocaloric food the next week, each subject serving as his or her own control. The results from all the groups are pooled and discussed at the end of the third week.

**Cardiorespiratory Function**

This lab has the dual propose of introducing students to a variety of measurement techniques for humans and also asking them to find statistical relationships among the measures. They measure the following parameters on themselves and one another: recting heart rate and blood pressure; height and weight; lung capacity (forced expiratory volume in 1 s and other respiratory measures); estimated maximum oxygen consumption by the step test and a bicycle test; and actual maximum oxygen consumption (using a metabolic gas analyzer) on those subjects that are willing and able. After being given a bit more background in statistics, they then sit down at the computers to play with the data and see whether they can find support for hypotheses that they propose. Usually they find that resting heart rate shows a nice strong negative correlation to any and all measures of fitness such as self-rated exercise frequency and estimated and true maximum oxygen consumption. They look for male-female differences, relationships of respiratory measures to oxygen consumption, and anything else they think of. Students get very excited about finding these relationships. It has been important to have enough computers so that only two or at most three students share a computer, to provide each with a chance to develop skills and test ideas.

For each lab except the fish dissection, students are required to write up the experiment in the form of a scientific paper. They are given a good deal of guidance [from chapters in Ambrose and Ambrose (1) as well as handouts] on form and style. The introduction, for example, must provide context, some background from previous primary studies, and a rationale and hypothesis for the experiment. Methods, results, and discussion sections must be similarly complete and professional in tone.

**OUTCOME**

From the reports of current students and alumni, we hear that these project labs are highly motivational. Although graduates who have gone on to medical school sometimes tell us that they have received fewer details in their labs and courses than those from other colleges, they always remark as well that their conceptual groundwork is firmer (N. Lowry, N. Jacobson, and S. Santen, unpublished data). Those who go on to graduate school come back to tell us that their laboratory experience at Hampshire College inspired them. They frequently mention the vividness of their lab experiences and the feelings of frustration and triumph from a particular experiment.

We have noticed that students develop a great sense of responsibility, often taking on tasks that help the whole class as well as their own piece of the work. Because they have designed the experiments themselves and the answers are often not known, they become passionately interested in the results.
As a consequence of this interest, students become intensely aware of the need for good technique; they take responsibility for their work in a simple but impressive fashion. This attitude is visible in the lab as they work and interact with their co-workers. In addition, students are often self-critical in their lab reports, pointing out numerous flaws in experimental design and chances for improvement.

An exciting offshoot of this lab design is the students' enthusiasm for using computers for data acquisition and statistical analysis. Often the students who are most fearful of mathematics take to computers extremely well in this hands-on approach. Although these few exposures cannot completely allay some students' fear of statistics, the opportunity to feel each step of the way in using various tests seems to convince students that the techniques are useful and within their grasp.

DIFFICULT PATCHES AND THINGS TO WORK ON

Although we feel confident in general about this project approach, there are areas in which we can improve. The written lab reports take a great deal of student time in addition to the normal work of the course. It may be possible to require a complete write-up for only one project, requiring only outlines and one or two completed sections for the other main projects. This year I tried having students present the results of their EMG lab to one another as a poster session, which was well received.

Students have mentioned that discussion of lab results is very useful, but such sessions can be very time consuming. We are working on having more short presentations and comparisons of results without taking too much time.

The experimental designs for the first project on EMG have not been very good in a number of cases. This year I tried introducing concepts of biomechanics before the first day of this lab to give students time to think intelligently about designs. Also, I asked each student to come up with a project idea; I led a brief discussion of the ideas, after which the students formed groups to carry out experiments on the best ideas. The general quality of ideas was improved.

FINAL COMMENTS

We have found such project-oriented labs to be motivating in several areas at Hampshire College, including physics, plant physiology, geology, ecology, and biophysics (2, 7, 12, 13). In part, we are able to do these labs because of our small class size. In larger class settings, however, the redirection of resources from numerous demonstration setups to fewer hands-on experiments could make project labs feasible. I have tried to indicate ways in which project ideas can be structured (e.g., by assigning a certain experimental design that must be used in the EMG lab or by specifying a set of variables for the cardiorespiratory lab). These structures, while restricting student creativity somewhat, could make it possible to carry out project labs within larger classes. Although coverage of a large number of different techniques and body systems in lab must be sacrificed in order to make time for projects, we have felt the results to be worthwhile in terms of motivation and depth of learning. The three or four projects possible in a semester allow for coverage of the major laboratory techniques in a field. Other material is covered in lectures and through the text.

Although we have been fortunate to obtain good numbers of computers and other sophisticated equipment, the principles of experimentation remain the same whether the equipment is old or new, simple or complex. Many measures on humans [for example, the sweat measures mentioned by Randall and Burkeholder (9)] can be quite simple. The important element is the commitment to experiments in which students go beyond simply imbibing information or demonstrating well-known principles, to actively inquiring.

I am deeply indebted to my colleagues, especially Merle Bruno, for teaching me so much about teaching, as well as simply being fun to work with.

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