ABSTRACT: Is it possible to design a laboratory experience that immerses the students in the scientific method and generates student ownership and enthusiasm of physiological concepts and applications? An example of such a course that uses student designed laboratory experiments is described here. The laboratory periods for this one semester, junior level, 4 cr. Vertebrate Physiology course are arranged into several 3-4 week sections. The first week is a design week in which student groups ask a question, pose a hypothesis and design an experiment. Week 2 is used to implement the design and collect data. Week 3 is used for group presentations where results, statistical analyses, and literature comparisons are combined to accept or reject the original hypothesis. Students reported that they enjoyed this type of lab experience because they are posing and answering questions for which they have ownership. Advantages and pitfalls of using this methodology are also described.

KEYWORDS: student designed laboratories, physiology laboratory, active learning, human physiology, lab planning, scientific method.

INTRODUCTION

The purpose of having a laboratory experience in any biology course is to get students actively involved in doing science, to have them experience first hand the courses of the information that are being presented in lectures and to gain an understanding of how concepts and ideas are applied to help us better understand how the natural world works. Many studies have shown that students develop more personal ownership when they are directly involved in picking the topics for investigations. They develop more personal ownership, increase their own intellectual investment in the projects and ultimately learn more and remember more because of this personal ownership of the experimental process (Cross, 1987; Gilchrist, 1997; Kolkhorst, et al., 2001; National Research Council, 2000; National Science Foundation, 1996; Rao and Di Carlo, 2001). How can we get more student ownership and intellectual investment in laboratory investigations in biology? How can we get faculty intellectual investment in the course topic transferred enthusiastically to the students? The purpose of this paper is to present some ideas and stimulate some risk-taking by Bioscene readers to use students designed labs in their courses.

We all know what kind of methods, techniques and content should be included to help our students learn in a hands-on learning environment. What should they be able to do when they have finished with their laboratory experience? What would be a good set of laboratory outcomes for biology majors and non-majors? Can a course be designed that includes many of these outcomes and promotes student ownership of concepts and the process of science too?
Table 1. Doane College Biology Department Statement of Student Outcomes (with permission from the Biology Department Faculty at Doane College, Crete, NE)

<table>
<thead>
<tr>
<th>Number</th>
<th>Category</th>
<th>Details</th>
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<tbody>
<tr>
<td>1.</td>
<td>COMMUNICATE EFFECTIVELY IN SCIENCE</td>
<td>Written, Oral, Leadership Skills, Collaborative Learning</td>
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<tr>
<td>2.</td>
<td>USE AND UNDERSTAND THE SCIENTIFIC METHOD</td>
<td>Problem Recognition, Hypothesis Generation, Experimental Design, Data Collection, Data Analyses, Interpretation of Results, Use of Scientific Literature.</td>
</tr>
<tr>
<td>4.</td>
<td>USE THE TOOLS AND TECHNIQUES OF SCIENCE</td>
<td>Appropriate Instrumentation, Computers, Statistical Methods, Observational Skills, Safety Techniques.</td>
</tr>
<tr>
<td>5.</td>
<td>BE SCIENTIFICALLY LITERATE</td>
<td>Environmentally Aware, Health Conscious, Appropriately Skeptical, Knowledge of the World of Science.</td>
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The laboratory schedule in a physiology course that is described here attains many of these outcomes including scientific writing, oral presentation, team learning and cooperation, all aspects of the scientific method as mentioned in Table 1, use of equipment, computers, statistical methods, and observation skills.

**COURSE DESCRIPTION**

This course is a 4 cr., one semester, 15-week, junior level, Vertebrate Physiology course. It usually has an enrollment of 20 – 32 students. The students take one of the two, 2 hr laboratory sections that meet one day per week. An outline of the lab schedule for this course is shown in Table 2. The first two lab periods in the semester are used to introduce ideas and practices that are a part of student designed labs. Many students are not used to designing lab experiments. Standard introductory material is discussed, i.e. how to write a lab report, how to use basic statistics, and how to plot data using Excel. Also in the second lab period they practice designing a lab experiment that addresses a specific hypothetical hypothesis. (For example: Vasoconstriction happens quicker and with a bigger decrease in volume pulse in athletes compared to non-athletes; or Blood pressure and heart rate increase and decrease faster in smokers compared to nonsmokers; or leg muscles are stronger than arm muscles in short vs tall people.) They pick their lab teams (a minimum of 2 and maximum of 3 people per group; 3 work better) and spend about 30 minutes discussing what they can do to test the hypotheses. They discuss equipment, sample size, techniques, and come up with a plan that they present to the other groups in this lab period. The other groups and the instructor critique the experimental design for strengths and weaknesses as well as limitations for experimental procedures and available equipment. Through this exercise they get a better feeling for what is expected of them next week when they must design an experiment and actually carry it out the succeeding week.

**Table 2: Outline of Lab Schedule for Vertebrate Physiology**

<table>
<thead>
<tr>
<th>Week 1:</th>
<th>Introduction to Laboratory; How to Write a Lab Report; Statistics Review; Basic Physiological Processes and Terminology</th>
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<tr>
<td>Week 2:</td>
<td>Lab Design Critique Sessions</td>
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<td>Week 4:</td>
<td>Execute Week – Students do the experiment planned the preceding week</td>
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<tr>
<td>Week 5:</td>
<td>Re-execute Week – Students redo the previous experiment with improvements (Written Draft of 1st week results due)</td>
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<tr>
<td>Week 6:</td>
<td>Report Week – Each team gives informal oral report on experimental results</td>
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<tr>
<td>Week 7:</td>
<td>1st hr: Planning/Experimental Design for Next Week: Cardiovascular Physiology 2nd hr: Bioethics Discussion: Animals in Research (Formal Written Lab Report Due with results from 2nd week)</td>
</tr>
<tr>
<td>Week 8:</td>
<td>Execute Week - Students do the experiment planned the preceding week</td>
</tr>
</tbody>
</table>
Week 9: Report Week – Each team gives informal oral report on experimental results (Formal Written Lab Report Due with results)

Week 10: 1st hr: Planning/Experimental Design for Next Week: Respiratory Physiology 2nd hr: Current Events Discussion: Enhancing Athletic Performance

Week 11: Execute Week - Students do the experiment planned the preceding week

Week 12: Report Week – Each team gives informal oral report on experimental results (Formal Written Lab Report Due with results)

Week 13: Planning and Initial Topic Selection for Final Powerpoint® Pathophysiology Talk

Week 14: Further Team planning/instructor consultation for Powerpoint® talks

Week 15: Teams present Powerpoint® Talks

The next four weeks in lab are spent on skeletal muscle physiology. The first two units (Introduction to Laboratory and Lab Design) are not repeated and students spend the first week designing the experiment. Early in this planning period, they are presented with a “Stimulating Ideas” list. This list contains some possible topics, which they could use to design an experiment. The idea sheets used for muscle and respiratory physiology are shown in Table 3.

These sheets also contain citations for some published papers, most of which are from the Journal of Applied Physiology, that the students can use to get ideas of what methods others have used, what sample data might look like and a discussion of their meaning as well. JAP can be searched easily online by going to http://jap.physiology.org. It is suggested that they look at a few of these papers and topics before they come to the first planning session so they may have some ideas to start discussing with the instructor. These idea sheets are also posted on the Blackboard so students can access them prior to coming to class. They are presented a list of possible equipment to learn about skeletal muscle function as well as what kind of animals might be available for their use. The group uses a planning sheet (Table 4) to help them write out the questions and hypotheses to be tested, equipment to be used, exact sampling protocol, sample size and what each team member will do in preparing and carrying out the design. This process is done in close conferencing with the instructor who approves their experimental design. This is also a good time for the instructor to demonstrate the use of the equipment so they will know how to use it next week.

The second week is the “execute” week. Students collect data during regular lab time and “outside of class” during times it is convenient for subjects to be sampled. But they must collect data that week. For many of these students, it is their first attempt at designing lab exercises especially in physiology. They usually have some problems, but do manage to get some data. Analyzing the results of their experiment helps them identify weaknesses, so the 3rd week is a “repeat-the experiment-with-modifications” week. They also consult with the instructor after their first attempt and talk over the needed modifications to be more successful and get better data. The data from the first execute week are put into a lab report draft. The instructor reads the draft and gives them feedback about their writing and ability or inability to follow standard, scientific-writing, report format. The 4th week of this first lab sequence is used for group presentations. Experimental hypotheses, methods and results including statistical analysis are summarized on a one page transparency or Powerpoint® slide and presented to the rest of the class. Class members ask questions, suggest improvements and learn some physiology from other groups. The formal, written lab report is due the next day. Thus, any suggestions or modifications received during the presentations can be included in the lab report for the next day. This sequence is repeated for the rest of the semester. Cardiovascular and respiratory labs are performed in 3 week sequences: one week for design, one week for execution and one week for presentations (Table 2). They are only given an additional execution week for the first muscle lab sequence. By the time the third lab sequence is undertaken most teams can design a sound experiment, collect good data and present results in a meaningful way.
### Table 3. Stimulating Ideas for Planning Skeletal Muscle and Respiratory Physiology Lab Experiments

#### TOPICS TO GET YOU THINKING ABOUT SKELETAL MUSCLE PHYSIOLOGY:
- Test and compare isolated frog, toad or salamander muscles.
- Compare maximum contraction tension in relation to rest time, effects of stimulus voltage, stimulus frequency, tetanus, fatigue, injection of chemicals, active vs. passive tension in different muscles or antagonistic muscles, and affects of muscle load on contraction strength.
- Test in vitro vs. isolated frog nerve and muscle prep – nerve stimulus vs muscle stimulus.
- Compare latency, contraction, and relaxation time in different muscles.
- Human muscle testing - antagonistic muscle strength, fatigue, diet effects
- Isotonic vs isometric lifting, endurance vs strength; compare different groups of athletes in muscle tests or effects of practice; end of season vs beginning of season; muscle diameter or length vs strength or agility.
- Effect of lower blood flow on muscle exercise in forearm using a bp cuff.
- Sarcomere length and volume comparison between muscles, between animals.
- Time of appearance of fatigue between right and left side muscles.
- Effects of STIM voltage, frequency or skin position on motor points in arm or leg muscles.
- Temperature effects on muscle function.

**Papers in J. of Applied Physiology (JAP) to read for ideas:** (Search JAP on line at [http://jap.physiology.org/](http://jap.physiology.org/))

- Strength induced enhancement of mechanical work production in frog single fiber and human muscle. JAP 83: 1741-1748, 1997.
- Reduced reflex sensitivity persists several days after long-lasting, stretch-shortening cycle exercise. JAP 86:1292-1300, 1999.
- Role of extracellular Ca in fatigue of isolated mammalian skeletal muscles. JAP 84: April 98.

#### TOPICS TO STIMULATE THINKING ABOUT RESPIRATORY PHYSIOLOGY:
- Role of CO₂ in control of breathing: effects of hyperventilation & hypoventilation
- Effects of smoking on lung volumes; variations in Forced Expiration. Volume (FEV)
- Broncho-inhaler effectiveness
- Asthmatic breathing and volumes
- Variation in forced expiratory reserve
- Temperature effects on breathing
- Humidity effects on breathing
- Height, weight, sex, athletic background correlations
- Oxygen consumption rates in small animals; construction of a thermal neutral zone or upper and lower critical temperatures in mammals; compare exothermic and endothermic animals’ responses to temperature change
- Variation in rate of CO₂ production using Fyrite apparatus
- Pattern of breathing with exercise; measurement of alveolar CO₂ and dead space volume
- Measurements of rib cage changes in humans with different breathing – estimates of volume
- Relationship of metabolic rate to body wt and surface area in mice or rats

**Papers in Journal of Applied Physiology to read for ideas:**

- Smaller lungs in women affect exercise hyperpnea JAP 84: 1872-1877, 998.
- A technique to measure the ability of human nose to warm and humidify air. JAP v87: 400.
Students in these labs truly take ownership of their experiments. Initially, they are rather slow at coming up with a testable idea but with guidance, they select plan they like. It is mentioned above that the first exercise of data collecting is frustrating. However, after they learn about their own limitations and the limitations of the equipment and test subjects, they proceed enthusiastically collect some valid data. Because of this enthusiasm, many students take more time to delve into published literature and specialized physiology textbooks to get specific answers to the questions that their results have generated. It gives them a chance to apply basic physiological concepts that they have been presented in lecture and other more detailed physiological references from the literature. It makes writing these reports, and making sense of their results a personal and group challenge. Some of the explanations presented by students that bring concepts and applications together have been rewarding.

Another advantage is that group work is emphasized and required. Almost all the groups, staying together for the entire semester, cooperate well. It is suggested that they take turns writing the sections of the lab reports and most groups do this. In these groups they learn how to collect data efficiently, analyze, plot and assess it, and reflect on the results in relation to the original hypothesis. It is a good example of students teaching students, each student benefiting from the experiences of other members of the group.

Another important aspect of this kind of lab is that most of the equipment is durable, easy to operate, and inexpensive to use. With the exception of the 6 Sure-Step Blood Glucose meters which utilize strips that cost $40 for 50, all the others (strip chart recorders used for muscle physiology, volume pulse measurements, EEGs, EMGs, ECGs, and breathing volumes) meet these criteria. Digital blood pressure cuffs by A&D Medical are portable and easy for the students to use. Respiration belts, heart rate monitors and temperature probes made by Vernier (http://www.vernier.com) can be connected directly to student laptop computers so that the laptops become chart recorders and data storage stations.

One other aspect of this lab planning sequence is that most student groups can adequately plan their experiment, discuss it with the instructor and attain approval in about 75 minutes. This leaves the rest of the two-hour lab available for the students to “sit around and talk physiology”. Often students do not get a chance to informally apply some of the topics presented in lecture to everyday situations. Each period a student brings in a magazine or newspaper article that includes some aspect of physiology that has been discussed or that they have questions about and the group discusses it informally. In another lab session, students bring in articles, rumors or questions about the physiology of enhancing athletic performance. Good discussions are generated between students who are athletes or students who may be interested in a daily workout plan and how it will affect them. Another important topic that is discussed in these post lab-planning sessions is the use of animals and humans in research. Possible alternatives to dissection and use of frog gastrocnemius muscles are discussed. The use of humans in clinical trials and the advantages, disadvantages and implications of placebos, gender and sample sizes are discussed. Ethical questions including when human life ends and what measurable signs of life are needed to keep an individual on life support have sparked heated discussions in the past. It gives the students a chance to ask questions, hear opinions of others, and further develop their own background knowledge and opinions on some important everyday issues in physiology and bioethics.

### Pitfalls of Student Designed Labs

It is necessary to enforce the rule about the minimum number of experimental units per group. They must have a minimum of 3 units so that minimal comparative statistics can be preformed. When the minimum sample size is used, the statistical tests may return the verdict of “no statistical difference between groups”; therefore, they must be urged to use as large a sample size as possible. Many students have had previous experience in which they obtained no significant difference and interpreted this to mean that they didn’t obtain reliable results or that the experiment was useless. Sometimes this may be correct but many
times students must be asked to look again to see the reason the treatment produced no significant difference.

Usually each semester complaints surface about some members not contributing equally to the group. It is necessary to monitor group activity closely during the semester and determine, by the quality of the lab reports, which members have not been performing adequately. This has continued to occur in about 10% of the groups over the past 5 years. It is difficult to prevent.

Another problem is synchronizing lecture material with its use in lab. Sometimes due to the timing of lecture, the background information that they need to design a thoughtful, effective experiment has not been covered in lecture by the time the lab planning session arrives. Alleviation of this problem can be accomplish by giving specific background information on the suggested topics in the beginning of the lab planning sessions. It is best if at least 3 lectures on the physiological topic are given before the students plan the lab on that topic.

A challenging aspect of this type of lab is suggesting new twists or variables in an experimental design. This takes imagination by the instructor, but including an unknown in the design makes the experiment more challenging and fun. For example, one of the “low energy” groups might design an experiment to test the hypothesis that “when we run uphill, our heart rate will increase”. Some variables that can be included in testing this hypothesis are utilizing people of different ages, genders, heights, leg lengths, leg diameters, before and after drinking a 16 ounce can of Mountain Dew, before and after a cigarette, or on a 75°F afternoon vs. a 25°F afternoon. Including some unknown variable, whether or not students can find specific references to it, makes it more of a challenge, and introduces them to aspects of physiology that might not have occurred to them.

CONCLUSIONS

Student designed labs at Loras College have immersed the students in the scientific method to a greater degree than any other type of lab environment in which the author has participated or discussed with other biology instructors. The teamwork, critical thinking, problem solving, data interpretation, and hypothesis-posing give the students the chance to think for themselves and use the physiological concepts in an applied context. It does increase student learning by increasing student ownership of not only the information but the process of scientific investigation. A discussion of any aspect of the lab planning sequence mentioned above or answers to any questions can be obtained by contacting the author at 563-588-7767 or tdavis@loras.edu

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Kirkville, MO
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