Tested Studies for Laboratory Teaching
Proceedings of the Association for Biology Laboratory Education
Volume 38, Article 41, 2017

Inquiry Labs for a Sustainable Low-Cost Biology Instruction Program

Amanda Masino and Kathy Schwab

Huston-Tillotson University, Department of Natural Science, 900 Chicon St, Austin TX 78702 USA
(**ammasino@htu.edu; kwschwab@htu.edu**)

Hands-on laboratory experience is critical for lasting student gains in scientific knowledge and skills. At Huston-Tillotson University, we sought to refresh our biology lab curriculum in order to increase student scientific reasoning ability, concept comprehension, persistence in science career path, and self-identification as scientists. We also wanted to integrate the curriculum so that we could embed more forms of collaborative learning throughout the degree plan and progressively prepare students for independent research projects. In order to do this effectively, we had to introduce labs that could be maintained at a low cost for program sustainability. We implemented a series of inquiry-based lab exercises in our core Natural Science courses to meet these aims. This short article reviews two of the labs we implemented: a two-session photosynthesis lab, and a one-session *Daphnia* physiology lab that were used for our General Biology courses.

Keywords: general biology, photosynthesis, Vernier, daphnia, physiology, inquiry-based learning

Introduction

Providing laboratory instruction that is well integrated into the course and into the curriculum generates significant benefits to students. Hands-on reinforcement through a laboratory exercise simultaneously improves scientific knowledge and scientific skills. In addition, lab-based instruction engages multiple learning styles, encourages collaboration, and communication, and, if structured properly, introduces students to authentic elements of the scientific research process. Establishing or maintaining an up-to-date laboratory instruction program, however, can require significant costs for start-up and implementation. This may present a significant barrier to small schools, those with limited laboratory fee budgets, or any college or university facing enrollment crunches and budget controls.

Huston-Tillotson University (HT) is a small liberal-arts focused HBCU (historically black college or university) in Austin, TX. We have fewer than 100 undergraduates; about 7.8% of these are Natural Science majors. In order to deliver effective instruction in the face of a limited equipment and supply budget, we have begun converting traditional "cookbook" style labs into inquiry lab exercises. We have structured the labs so that, after an initial period of investment in equipment, we can maintain the program at a relatively low cost.

Two Approaches to Inquiry-Based Labs

Inquiry-based lab instruction emphasizes the development of the student's ability to think scientifically. As with any lab, students get hands-on experience to reinforce scientific concepts. In inquiry labs, however, students design portions of the experimental protocol themselves, which builds their understanding of the scientific method. Inquiry is also a powerful tool for improving student engagement and self-concept as scientists, a particular concern with students from underserved groups. We decided to re-structure key exercises in our Year 1 and Year 2 core natural Science courses as inquiry labs.

Our implementation generally followed one of two models. We followed a two-session inquiry model for labs that students would encounter early in the course. In this approach, students are given an experimental protocol (detailed or general) to follow in an initial laboratory session. They learn techniques, and collect and analyze data as they would in a typical lab. The inquiry element is introduced during the second session when students then pose and test their own question that is an extension of the finding from the initial work. The instructor offers real time feedback on the experimental plan during planning session. We found that this approach is well suited to new or complex methodologies, or, as mentioned previously, early in the semester when students are still getting comfortable working in the lab setting. The two-session photosynthesis lab that follows is an example of this approach.

For labs that occur later during the course, or that do not require practice with specialized equipment, a one-step inquiry approach was taken. Students are provided with relevant background information and a research question. They devote one class session to discussion and planning; it is during this session that the instructor can offer real-time feedback on the experimental design. Then the students conduct their experiments during one laboratory session. The *Daphnia* lab exercise that follows the one-session model.

Student Outline
Photosynthesis Lab Week 1 – Investigation with Spinach Leaves

Background

Plants make sugar, storing the energy of the sun into the chemical process of photosynthesis. This process uses light energy to convert carbon dioxide and water into sugar and releases oxygen (which animals need to breathe).

$$6\ H_2O + 6\ CO_2 + \text{light energy} \rightarrow C_6H_{12}O_6\ \text{(sugar)} + 6\ O_2$$

When they require energy, they can tap the stored energy in sugar by a process called cellular respiration. The sugar, or glucose, using oxygen is broken down into carbon dioxide and water with the release of energy that was stored in the covalent bonds of the sugar molecule.

$$C_6H_{12}O_6\ \text{(sugar)} + 6\ O_2 \rightarrow 6\ H_2O + 6\ CO_2 + \text{energy}$$

All organisms, including plants and animals, oxidize glucose for energy. Often this is used to convert ADP into ATP.

Objectives

In this two-week lab sequence, you will

- Measure oxygen production or loss during photosynthesis
- Measure carbon dioxide production or loss during photosynthesis
- Study the effect of light on photosynthesis
- Explore additional factors that affect photosynthesis
- Design and run an experiment

Materials

Spinach leaves
Aluminum foil
Labquest 2
CO_2 Gas Sensor
O_2 Gas Sensor
BioChamber 2000
Lamps
Beakers.

Procedure

1. Obtain some spinach leaves from the instructor. Dry them with a paper towel if they are wet, then place into the plastic biochamber.
2. Place the two gas sensors in the openings on the top of the biochamber. Be sure to get a good seal.
3. Cover the entire chamber in aluminum foil to completely block light. Wrap sensor cords carefully, please!
4. Make sure that the switch on the CO_2 Gas Sensor is set to Low. Connect the CO_2 Gas Sensor to Channel 1 and the O_2 Senor to Channel 2 on the Labquest 2.
5. Turn on the Labquest 2.
6. Click "Sensor" and change both O_2 and CO_2 to ppt.
7. Click "Sensor" and zero the CO_2 and the O_2.
8. Wait 10 minutes for readings to stabilize.
9. Start collecting data. Record CO_2 and O_2 levels every minute for 15 minutes in data table 1.
10. After 15 minutes of data collection, remove the aluminum foil. Place a container of water between the light and the biochamber. Turn on the light.
11. Wait 5 minutes.
12. Start collecting data, record CO_2 and O_2 levels every minute for 15 minutes in data table 2.
13. Remove the leaves, unplug and store the probes, and clean and dry the chamber.

Data Tables

Table 1. Gas measurements under dark conditions.

Time (min)	CO_2 (ppt)	O_2 (ppt)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Table 2. Gas measurements under light conditions.

Time (min)	CO_2 (ppt)	O_2 (ppt)
0		
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Analysis

1. Graph both sets of data in Excel. Reminder: you will have two y-axes, one for CO_2 and one for O_2 levels.

2. Determine the rate of O_2 and CO_2 change under each condition by subtracting the gas measurement at time 0 (initial) from the measurement at 10 minutes (final), then dividing by 10:

$$\frac{\text{Final (ppt)} - \text{Initial (ppt)}}{10 \text{ minutes}} = \text{Rate (ppt/min)}$$

You will have four calculations: the rate of CO_2 change in the dark, the rate of O_2 change in the dark, the rate of CO_2 change in the light, and the rate of O_2 change in the light.

3. Were either of the rate values for CO_2 a positive number? If so, what is the biological significance of this?

4. Were either of the rate values for O_2 a negative number? If so, what is the biological significance of this?

5. Do you have evidence that cellular respiration occurred in the leaves? Explain.

6. Do you have evidence that photosynthesis occurred in the leaves? Explain.

7. List five factors that might influence the rate of oxygen production or consumption in leaves. Describe in detail how each would affect the rate.

Photosynthesis Lab Week 2 – Test Your Own Hypothesis

Now that you know how photosynthesis works, you will design and run an experiment of your own.

1. Choose one of the factors you predicted to impact photosynthesis during your analysis. Use that information to generate a hypothesis: a specific and testable prediction you can test about how that factor would influence photosynthesis. Keep in mind that you will have access to the same instruments to test your hypothesis.

You can choose to focus on CO2 production, O2 production, or both.
You may request different plant types.
You will have access to basic labware and non-hazardous chemicals.
You will be able to use additional instruments if desired (thermometer, pyranometer, humidity sensor).

2. Make a 5-7 minute presentation to the class on your plan. Be detailed! State your hypothesis and describe your protocol. Be sure to identify your dependent and independent variables.

3. You will have only one lab session to perform your experiment, so plan time carefully.

4. You will generate your own data tables and graphs.

5. Analyze your results and make conclusions. We will present these in class as well

References

Week 1 experiment was adapted from Vernier's "Photosynthesis and Respiration" lab exercise in Biology with Vernier at Vernier.com

How Does the Environment Impact an Aquatic Species?

Objective

During this lab, you will design and conduct experiments to measure how the heart rate of an aquatic organism, the invertebrate *Daphnia*, is affected by temperature and/or the presence of selected waterborne chemicals.

Background

Daphnia are small (1 5 mm) crustaceans that live in aquatic environments as components of the plankton. As such, they are an important constituent of the base of the food web. *Daphnia,* or water fleas, are also useful indicator organisms– because they can't easily swim away from toxins, we can study *Daphnia* to get an idea of what chemicals are present in a body of water.

Daphnia have an uncalcified shell made of chitin called a carapace. Like other crustaceans, they have a head, thorax, and abdomen, with body segments bearing specialized appendages. Daphnia filter feed – that is, they sift unicellular organisms (unicellular algae, bacteria and fungi) from the water. You will probably be able to see food particles being swept into the *Daphnia'*s labrum, or mouth groove, as a water current is generated by the organism's short flattened thoracic appendages. These thoracic appendages also serve as a respiration organ as they circulate oxygenated water through the organism's hemolymph (blood-like body fluid). You may also observe a darkened line of food particles in the foregut, midgut, and hindgut.

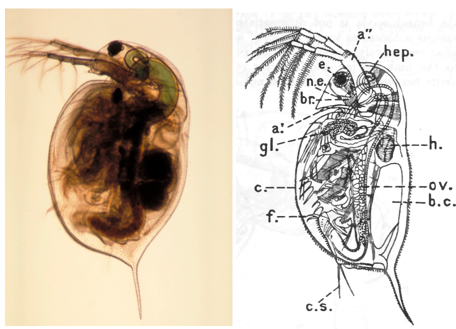

Figure 1. *Daphnia* anatomy. a', antennule; a'', antenna; bc, brood chamber, br, brain, c, margin of carapace; cs, caudal setae, e, eye; f, furca,, gl, maxillary gland (shell gland); h, heart; hep, hepatic diverticulum; ne, Nauplius eye; ov, ovary.
(Figure credits: *Daphnia* photo, creative commons license, from Are We Underestimating Species Extinction Risk? *PLoS Biology* 3/7/2005, e253 doi:10.1371/journal.pbio.0030253; *Daphnia* schematic, public domain, from The General Bauplan of *Daphnia* species, E. Ray Lankester, 1909)

Daphnia get their nickname, water flea, from their jerky swimming motion. This action is carried out by the large second antenna visible near the organism's compound eye. *Daphnia* sense light and even change their movement pattern in response to it. *Daphnia* alternate between sexual reproduction and an asexual reproduction called parthenogenesis. You may see either an egg or parthenogenetic clones growing in the female *Daphnia*'s dorsally located brood chamber.

The dorsal heart circulates the hemolymph through the *Daphnia*'s open circulatory system. *Daphnia* use a version of the same oxygen-carrying protein that humans do, hemoglobin. In this lab, you will be using the heart rate as a measure of *Daphnia*'s physiologic state. The heart rate is rapid! Spend some time observing *Daphnia* and practicing heart rate counts.

Materials

You will have access to

- *Daphnia* cultures
- dissecting microscopes
- slides
- timers
- thermometers
- ethanol solutions (5% and 10%)
- ibuprofen solutions (5% and 20%)
- lab glassware

Experimental Design

During this lab period, you will design your experiment. Review it with Dr. Schwab before proceeding with the experiment. Generate a step by step method that includes not only what you will do but also how you will measure it – be detailed!

Some things to include:

- Number of Daphnia tested per condition
- Number of conditions (5% ethanol, 4oC water) – aim for at least three
- Number of trials – how many times must you repeat to have statistical value?
- How are you measuring heart rate?
- Are you recording the Daphnia?
- How long to subject the Daphnia to the condition before measuring heart rate?
- Are you including a recovery phase? If so, how long?
- What are you using as a negative control?
- What are you including as a positive control?

After your design is complete, also answer the following:

1. State the specific hypotheses your experiment is testing.
2. Identify and list the variables you would keep constant in the experiment.
3. Identify and list your experimental variables.
4. Predict outcomes for the experiment and justify your predictions.

Conduct Experiment and Record Data

Follow the experimental design approved by your instructor.

Final Analysis

1. Describe your data. Include information about average values and/or graphs if appropriate.
2. How do your results compare to your initial predictions?
3. Were there any issues with replicability? That is, did all of the Daphnia tested behave similarly under the same conditions? If so, what does this mean? If not, what might have happened?
4. Were there any portions of the experiment that seemed inconclusive? Describe them.
5. Describe modifications that could be made to improve the reliability of this experiment.
6. Describe an extension of this experiment that would further investigate the same hypothesis.

Mission, Review Process & Disclaimer

The Association for Biology Laboratory Education (ABLE) was founded in 1979 to promote information exchange among university and college educators actively concerned with teaching biology in a laboratory setting. The focus of ABLE is to improve the undergraduate biology laboratory experience by promoting the development and dissemination of interesting, innovative, and reliable laboratory exercises. For more information about ABLE, please visit **http://www.ableweb.org/.**

Papers published in *Tested Studies for Laboratory Teaching: Peer-Reviewed Proceedings of the Conference of the Association for Biology Laboratory Education* are evaluated and selected by a committee prior to presentation at the conference, peer-reviewed by participants at the conference, and edited by members of the ABLE Editorial Board.

Citing This Article

Masino, AM, Schwab, KW. 2017. Inquiry Labs for a Sustainable Low-Cost Biology Instruction Program. Article 41. In: McMahon K, editor. Tested studies for laboratory teaching. Volume 38. Proceedings of the 38th Conference of the Association for Biology Laboratory Education (ABLE). **http://www.ableweb.org/volumes/vol-38/?art=41**