Discovering Biological Science

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Preface

Discovering Biological Science was written and adapted for introductory biology courses whose goals include helping students develop a deeper understanding of how scientific knowledge is generated and how to use/evaluate scientific knowledge to better understand real-world science related issues which confront them in their personal, professional and civic lives. In order to give students the tools to make informed decisions, this laboratory experience teaches them not only about key biological processes but also how we know about these processes. The strength of this laboratory manual lies in 3 areas:

1. The biological content and themes explored are those that are traditionally covered in undergraduate introductory biology courses.
2. Most lab instructors, who are often graduate teaching assistants, have little experience teaching using inquiry-based, collaborative & student-centered methods. The *Student Instructions* and the *Team Lab Notebooks (TLNs)* provides students with the structure they will need to engage in student-centered inquiry. The *Instructor Guide* educates instructors in relevant learning theory and provides pedagogical suggestions to help instructors effectively facilitate student-centered inquiry-based and collaborative learning.
3. The lab curriculum emphasizes the process of science at all levels. The labs are structured to give students practice with various levels of science, culminating in a multi-week team project in which students are engaged in the entire process of proposing, designing, conducting, writing, and presenting a scientific research project of their own design. On-going peer-review/critique of student research proposals, articles and presentations allows students to experience how the scientific community establishes the validity of scientific knowledge. In this way students experience the power that science has to reveal the workings of the natural world, the dynamic nature and tentativeness of this knowledge, and how the scientific community operates to establish the validity of scientific knowledge. It is these aspects of science literacy which will help students to use and evaluate scientific knowledge wisely as they make decisions in their personal, professional and civic lives.

This lab manual is written for undergraduate introductory biology and can be used in both biology-majors' and general education courses. The National Science Foundation and the American Association for the Advancement of Science have advocated for this approach in Vision & Change in Undergraduate Biology Education (http://visionandchange.org/finalreport/). This project was supported by grants from the National Science Foundation and the Howard Hughes Medical Institutes. More information about this project can be found at: http://petersj.people.cofc.edu/CCLI/.

How is Inquiry-Based Learning Different from the "Traditional" Approach?

Most would agree that introductory biology courses should help students develop a literate understanding of how scientists reveal knowledge about the natural world. It is also clear that students are more engaged and tend to learn better when they are actively doing, rather than passively listening. This is in large part why "hands-on" labs have always been an integral part of science classes. However, although traditional introductory science labs employ scientific methods, these labs usually prompt students to follow (often mindlessly) a set of instructions which are intended to yield answers or outcomes that are preplanned and already known, and which is intended to confirm a concept or

process presented prior to the lab. In short, the context for the lab is an abstract biological concept or process, presented prior to the lab. The highly directed nature of more traditional labs does not allow students to experience the creative aspects of science and may leave students uncomfortable with the tentative and dynamic nature of scientific findings.

In inquiry-based labs, observations and questions which are often centered on real-world and relevant issues, initiate and set the context for the lab exploration. This is because research in science education has revealed that students are more likely to be engaged in the lab exploration if there is an initial context which is centered on student interests, observations or experiences. Students are also more invested in the outcomes of the lab when they are allowed to make critical decisions about the design and execution of the experiment. The lab curriculum emphasizes the process of science at all levels, both how science is done in the lab (experiments) and also how the scientific community establishes the validity of scientific knowledge. In this way students experience the power that science has to reveal the workings of the natural world, the dynamic nature and tentativeness of this knowledge, and how the scientific community operates to establish the validity of scientific knowledge. These experiences are intended to help our students develop a more complete sense of whether basic or applied scientific research is of interest to them professionally. The approach is also intended help students learn how to use and evaluate scientific knowledge to make decisions in their personal, professional and civic lives. To do this most labs this semester are structured around a "5-E" cycle of learning which emerges from learning theory and which models the process of scientific discovery (see figure 1).

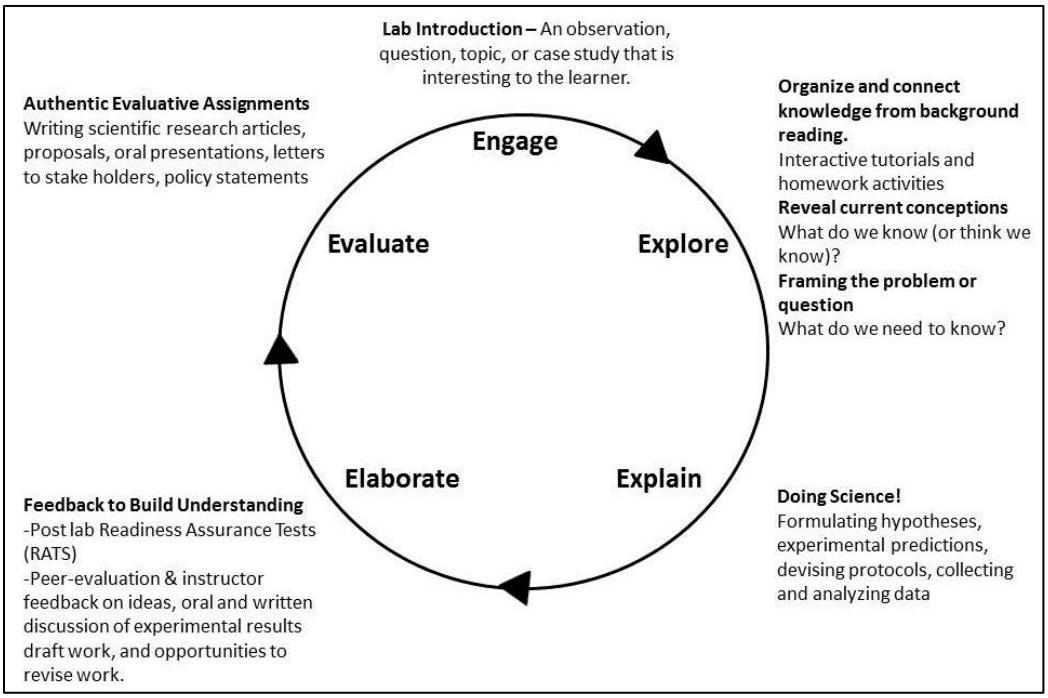

Figure 1. The Learning Cycle in an inquiry-based lab experience.

This lab curriculum will use both a guided and student-directed inquiry format. The differences between these teaching strategies and more traditional approaches are presented in the table below.

Table 1. Features of science laboratories categorized by stage of inquiry and teaching method. This lab utilizes guided inquiry and follow-up student-directed inquiry labs.

Stage of Inquiry	Traditional →	Guided-Inquiry (Practicing inquiry) →	Student-directed Inquiry (Performing inquiry)
Context for Inquiry	Concepts or processes covered in lecture or textbook	Student observations of nature or a relevant issue or case-study.	
Background research	Initial content lecture or reading provided to student	Assigned reading supplemented with independent research.	Students decide what background knowledge is required, and what learning resources to use.
Scientific question	Question provided by teacher	Students generate questions with some guidance	Students pose their own question
Evidence	Experimental methods and analysis procedures are provided to students	Students make some methodological and analysis decisions with guidance from the lab	Students decide on what evidence to collect and how to collect it.
Explanations	Students are provided questions to answer about their findings.	Students are provided general guidelines on what to discuss in their explanations	Students independently formulate their own explanations
Connections to concepts	Students are explicitly told which concepts to use through specific questions.	Students coached to make certain concept connections through independent research	Independently decided on in student research teams.
Communication of findings	Answering lab follow-up questions	Written discussion of findings with guidance from lab or instructor coaching.	Independently by students. Multiple forms of communication or media can be used. Peer review is stressed.

During early "practicing inquiry" labs students explore biological concepts and processes while developing their scientific inquiry skills. Students then build on knowledge obtained from the previous lab(s) to explore biological concepts and science process more deeply through a multi-week student-directed inquiry. Working in research teams, students will identify an aspect of a biological concept they wish to explore further. Within the context of a manageable framework, students work collaboratively to formulate questions, conduct, and analyze experiments of their own design. Final projects will be peer-reviewed and presented to the class as both a written article and an oral presentation. Quality research papers can be submitted to the Journal of Undergraduate Biological Investigations (JUBI) http://petersj.people.cofc.edu/JUBI/ for publication. In this way students not only learn **about** key biological processes, but also **how we know** about these processes and how scientific knowledge is shared and evaluated by the scientific community.

Finally, remember that learning is a process! Conceptions are not easily altered, and it will take time and constant and explicit reinforcement to alter misconceptions and deepen conceptual understanding. Table 2 presents some of the common misconceptions that college students often have about science. This semester's labs will be working to challenge and correct some of these misconceptions.

Table 2. Common **misconceptions** about science.

About nature of science:
• Scientific evidence is when a scientist says something is true. • Proof or establishing knowledge as factual (a fact) is the goal of science. • A scientific hypothesis and a scientific theory are essentially the same thing. • Well you know…"Evolution is just a 'theory'!" (i.e. Scientific theories are just guesses or hunches.)

- Scientific knowledge never changes...it yields unchangeable truths about the world.
- Science deals with naturalistic questions and naturalism in this context means “not artificial”, or not involving humans in any way.

About the relationship between science and technology:

- Science and technology is the same thing.
- Science aids in the development of new technologies, but technology has little influence on science.
- Science is done only to develop new technologies that improve life.

About scientific experimentation:

- Measuring something once gives us enough information to draw definitive conclusions.
- Measuring something many times on the same subject in an experiment provides evidence that can be generalized to all individuals in that population.
- Experiments “prove”, rather than provide support for a hypothesis.
- A hypothesis is equivalent to a random guess explaining an outcome.
- Correlation = cause
- If an increase in variable A results in a change in variable B, then this alone is evidence of a direct relationship between the two variables. (i.e. ignoring the importance of experimental controls).
- If the means (average) is different for the dependent variable, then the independent variable must be the reason. (i.e. ignoring variation, sample error, statistically significant differences.)

Scientific Attitudes:

- Only professional scientists are capable of doing science, or making good decisions about science related issues. (The “I’m not a science person” syndrome!)
- Science is a collection of facts and ideas to be memorized for an exam.
- Scientific theories become laws when they are proved.
- Science has little to do with our everyday lives.
- Science is only done to improve our lives (i.e. for medical purposes).

Science and Society:

- Scientists make decisions based on <u>completely</u> objective criteria alone, and scientists’ personal views, educational background, job pressures, interactions with colleagues play no role in scientific decision-making. Or the opposite, that scientists make decisions that are based solely on, or strongly biased by personal feelings/views.