Great Ideas! in Teaching Biology

A Benjamin Cummings Publication for Biology Instructors

Volume 3

TABLE OF CONTENTS

COMPANION WEB SITE

A wealth of resources related to these articles are marked with an icon and can be found at www.aw.com/bc/greatideas.

ABOUT THIS BOOKLET

Great Ideas is published as a service to introductory biology instructors. We welcome comments, contributed articles, and suggestions for future issues. Please contact the Editor at strategies@aw.com or Beth Wilbur at Beth.Wilbur@awl.com.

Welcome to the third volume of **Great Ideas!**, *brought to you by the biology publishing team at Benjamin Cummings. This annual publication is our way of bringing you insights and ideas (great ones!) for improving undergraduate biology education. In this issue you will find interesting and informative articles on lab reform, teaching with investigative cases, web-based tutorials, modeling exercises to help students grasp 3D structure, and the Advanced Placement biology program from which many of your incoming freshmen emerged. All of these articles reflect the talent and enthusiasm of the instructors who took the time to share their experiences with you.*

New to this issue are references to online materials that support and enrich the articles you will read in print. Whereever you see the logo at left, you can jump to our Companion Web Site (www.aw.com/bc/greatideas) to find additional images, citations, supporting documents, and helpful links that extend the usefulness of the articles. You will also find this and past **Great Ideas!** *issues available as PDFs. No passwords are required for access to the Companion Web Site — just type the url into your browser and look for the link to the Great Ideas resources.*

Benjamin Cummings is fortunate to work with a large number of such experienced and innovative educators as we produce learning materials for biology students. We salute them with this journal and will continue to support their commitment to excellence — first through our textbooks and materials but also by means of our Strategies for Success newsletter, Strategies for Success Workshops (see page 19), and our annual Biology Leadership Conference.

Please join us in thanking the contributors to this volume. We also gratefully acknowledge our faculty advisor, Dr. Richard Showman, University of South Carolina, who provided insight and advice as we shaped this issue.

REDESIGNING THE INTRODUCTORY BIOLOGY LABORATORY EXPERIENCE

Jean Heitz
University of Wisconsin, Madison

We all know that the study of biology, or any other science, involves more than assimilating factual information. It also involves learning how to use that information for problem solving, posing hypotheses, conducting experiments, and interpreting experimental results. Given this, if we want our students to understand what science is, we need to provide them with both conceptual knowledge and practice in using that knowledge. That is, we need to give them opportunities to practice the process of science. The laboratories associated with biology courses seem an obvious place for providing this practice.

With this in mind, in 1990, I began developing a Research Project approach to teaching labs in Botany/Zoology 151 and 152, a two semester, entry-level sequence for majors in the biological sciences. The key to this

continued on page 2

Redesigning the Introductory Biology Laboratory Experience
continued from page 1

new approach was to remove the requirement that a lab exercise be completed in one week. This change allowed me to design the labs so that students would do what scientists do — find answers to unknowns. In the redesigned labs, students make initial observations, develop hypotheses, outline the methods for examining these, and then conduct the experiments. They learn how to deal with their own data, how to use simple statistical methods to compare results, and how to write up their findings in scientific format. In other words, to the best of my ability, in the confines of a student laboratory, I designed the labs to give students an authentic experience with science.

In this article I discuss the types of labs I developed as well as what worked and what didn't. To do this, I use a specific Research Project lab (*Dead or Alive?*) as an example. For your reference, the complete lab write-up, with the instructors' notes and the two labs that precede it, are available on the Companion Web Site.

Allow Students to Practice the Process of Science

Many laboratory exercises include such specific directions that they read like cookbooks. The goal in such labs appears to be to follow a procedure as exactingly as possible and to produce some known answer with a given percentage of success. I don't deny that developing such care and attention to detail and technique is important. However, there is much more to both science and life — not the least of which is helping our students become independent thinkers and learners. One way to do this is to provide them many opportunities to practice the process of science. (See a list of supporting literature on the Companion Web Site.)

When we teach the process of science we give students the opportunity to:

- Apply their conceptual knowledge as they investigate novel questions or problems.
- Devise their own methods or protocols.
- Execute their proposed experiments.
- Analyze and interpret the data they collect.
- Develop logical arguments and other critical thinking skills.
- Report the results in both written and oral scientific format.

In a classroom setting we can facilitate the process of science by practicing a team approach. When students work in teams they can explore more complex and meaningful, "real-life" questions or problems. (See Figure 1.) This approach also develops students' abilities to collaborate and work effectively with others as part of team.

Figure 1 Student teams can explore more complex questions.

Redesign Labs to Emphasize the Process of Science

In 1990, I began modifying the design of our introductory labs to increase our students experience with the process of science. The lab exercises I developed can be loosely categorized as either "Tools and Techniques" or "Research Project" labs. Tools and Techniques labs are one-week labs that provide students with a review of microscope use, cellular techniques, basic methods of biological measurement, analysis of scientific articles, and statistics. Research Project labs are three-week modules designed to mirror real, open-ended problems in biology. In these, students are introduced to a problem and choose an aspect of it to study. They write a proposal (week 1), execute their experiments (week 2), analyze the data they collect, and report the results (week 3).

To provide students with a more gradual introduction to Research Project labs, the early Tools and Techniques labs also include small investigative problems. You can find an example, *What is Life?* 1 and 2, on the Companion Web Site.

In some of the Research Project labs (for example, *Dead or Alive?*), students are given a predetermined goal or purpose and asked to propose the most efficient and cost-effective method of reaching that goal. In other Research Project labs, students are introduced to a question, provided with some initial observations, and asked to develop and test a hypothesis to investigate some aspect of the question, (e.g., *Gravitropism and the Hypocotyl*). In yet others, students are asked to analyze existing evidence, look for possible correlations and, based on their analysis, propose a hypothesis for observable correlations, (e.g., *Skeletology*).

"Research Project" Labs Mirror Real-Life Research Problems

Designed to give students experience with the overall process of science, *Dead or Alive?* is the first Research Project lab we assign. This lab builds on the *What is Life?* Tools and Techniques lab which students do first and is introduced with the following:

What is the Research Project?

A major US oceanographic survey has just discovered entirely new forms of life in one of the deep oceanic trenches. This discovery led the survey team to take thousands of grab samples from nearby areas to determine if they provide evidence for more forms of life. These samples now need to be analyzed. Doing a complete analysis of each sample would be prohibitively expensive and time consuming. Therefore, the first step is to determine which of the thousands of samples are most worthy of more complete study and analysis.

The National Science Foundation, a granting agency of the government, plans to give the multimillion-dollar contract for the complete analysis to one major research lab. To determine which lab gets the contract, the NSF has provided competing labs with subsets of the samples. The lab that gets the contract will be the one that develops the most cost-effective and accurate methodology to determine which of the thousands of samples are most worthy of complete study and analysis. The protocol for determining which samples are most likely to contain evidence of life forms has been left up to the competing labs.

Your lab has requested and received one of the subsets of samples. If you get the contract, you will be able to support yourself and your employees for several years. In addition, the national recognition the contract provides will help your lab gain future contracts. You call a lab meeting to brainstorm how to determine which samples are most likely to contain evidence of life forms. Your staff, time and budget are limited.

To be effective, a research project cannot have a known or expected outcome. The first time we ran this lab we made the mistake of using identifiable samples (e.g., pond weeds, rubber duck, a feather). Students could not get past their knowledge of the sample's identity. The following dialogue reveals their typical response:

Instructor: "How could you determine whether the sample is alive or dead?"

Student: "It's a rubber duck."

Instructor: "I know that, but the question is what methods would you use?"

Student: "It's a rubber duck."

It became clear that, to the students, this was a "trick question." They thought that because the rubber duck (feather, etc) was a known quantity, there must be some hidden protocol (in their minds, the only right one) that their instructors expected them to come up with. They felt "set up" by this approach and did not want to look stupid for not arriving at the right answer. The solution? Use samples that cannot be readily identified.

We now present students with numbered vials of powdered or granular samples which are unfamiliar to most of them. We don't even tell the teaching assistants what the vials contain. Within a lab section, student groups get different sets of samples. To make up the sets, 12 different substances are chosen. Two vials of each substance (duplicates) are used per lab section. A lab containing six student groups gets six sets of four samples. At least one of the vials contains an inorganic substance. The other vials usually contain organic or live materials. Among the samples we use are dried yeast, diatomaceous earth, dried blood worms (fish food), freeze dried shredded beef, calcium carbonate powder, brine shrimp eggs, and small seeds.

When first introduced to this type of lab, students need some cues or suggestions to begin. For example:

Before you begin, you will need to:

1. Define "alive", "dead", "organic" and "inorganic" and develop operational definitions of each of these that can be used in experimentation. Your operational definitions will obviously be limited by the methods you will use.
2. Determine what test(s) you would need to develop to determine if something is:
   a. Alive
   b. Once alive, but now dead
   c. Never alive and not formed by something once alive
3. Determine how many tests are needed in each case.
4. Decide how you could most efficiently organize your team of scientists for this initial investigation.

Keep in mind, you need to define and justify all of these in your proposal to the granting agency.

After this beginning, students devise their own protocols to examine their subset of samples, execute their experiments, and analyze their results. Students then use the results of their analyses to develop the grant proposal and budget.

Let Students Learn from Their "Mistakes"

Students are given the opportunity to propose and try methods that may not work and to learn from those mistakes. This means that the instructor answers questions about what methods are available, but does not tell the students what to do. In addition, the instructor does not grade the students' preliminary (week one) proposal but simply provides review comments. The review comments come in the form of questions, not possible modifications to the methodologies proposed. For example: "Your reviewers are not necessarily familiar with the project. Have you provided them with enough information in the introduction to understand what you are doing and why you are doing it?" "Have you included adequate controls in your methods section?" Peer reviews of proposals are also included to help student refine their ideas.

Prior to writing their final *Dead or Alive?* grant proposals, students share their preliminary results. Each team explains what they did and why they did it. To facilitate this discussion (and all peer reviews) the lab manual includes the following instructions:

continued on page4

Redesigning the Introductory Biology Laboratory Experience
continued from page 3

In this study, you are assuming that the class is a research lab working together to get the contract for further analysis of the deep trench data. Whether or not you get the contract depends on how well the lab does as a whole. Therefore, it is in everyone's interest that each of the proposals be as good as possible. To assist each other in this regard, individual teams will:

- Report the results of their analyses of samples.
- Share ideas on what should be contained in each section of the final proposal.

Again, the instructor does not provide specific comments on each group's logic, but uses guiding questions and allows the groups to learn from what they did and what the other groups did.

To help students understand that their final proposals should reflect what they learned, the instructor encourages students to modify their preliminary proposal based on their experience. The instructor also makes it clear that the students' final proposals can (and most likely should) differ significantly from their week-one proposals.

To mirror actual proposal guidelines, specific requirements for their proposal submissions are also provided. (See "Requirements for Proposal Submission" and "Sample Proposal Format" in the complete lab offered on the Companion Web site.)

Change the Physical Design of the Lab to Support the New Curriculum

As we revised our laboratory curriculum, we also changed the physical design of the lab classroom. In this new design, the lab room is divided into two general areas. Six student workstations, each with its own sink, gas, and air, fill about two thirds of each lab room (Figure 2). Cabinets in the workstation and under the sink area are used to store student microscopes and commonly used supplies. Computers on moving carts allow students to work on proposals and drafts of final papers in lab. In

Figure 2 Student Workstations

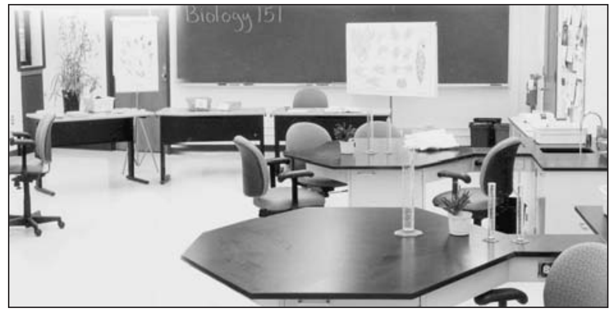

Figure 3 Movable Tables with Equipment

specific Tools and Techniques labs the computers are also used to teach students how to access specific biological resources on the Internet and in the library system on campus.

Supplies and other equipment for each lab are set up on a series of movable tables at the front of the lab, the remaining third of the room (Figure 3). This allows for great flexibility in set up, and allows the instructor to monitor use of sensitive equipment and chemical reagents.

This design has proven very effective for active lab work, small group work, lab discussion, and demonstrations. Students and the instructor have easy access to each other and to shared materials and equipment. The design of the student workstations promotes discussion and collaboration among team members. As a secondary benefit, students demonstrate more individual accountability for general lab maintenance.

What Have We Learned?

We ran the first test of the Research Project labs in Biology 152 in the 1990-1991 spring semester. The previous fall students took Biology 151 in the traditional manner. They were introduced to a new lab topic each week and, individually or in pairs, worked on prescribed lab protocols. Evaluation occurred in the form of biweekly quizzes. In the spring semester, these same students did five new Research Project labs in Bio 152. Small groups of three or four students worked together on each lab and produced a group report. The composition of the groups was changed for each new Research Project. We were pleasantly surprised to see that most of our students were transformed from people who previously ran out of lab as quickly as possible to students who worked on their projects willingly, both in and out of lab time.

Based on this experience, we converted all of our 151-152 labs to the Research Project format for the 1991-1992 academic year. We discovered (painfully) that students must be introduced to this form of lab gradually and that they need basic techniques and microscopy review. The Tools and Techniques labs were designed to meet that need.

Some might think that at this point we had the formula down. We knew what to do and everything was working. Not quite. Remember those transformed students from our first run of Research Project labs in Biology 152? Did we see the same transformation in the following semesters? The simple answer is "no."

While subsequent students tended to become more engaged in the Research Project labs than in the traditional labs, they didn't show the same interest or enthusiasm as did that first group. After much thought, I finally figured it out. Our first group experienced a semester of traditional labs before attempting the Research Project labs. They could readily see the difference. In addition, since we were using them to test these labs, we spent time explaining what we were doing and why we were doing it. I realized that subsequent groups missed both of these elements. The solution? Be very explicit about what you are doing and why you are doing it as you introduce this or any new lab format.

Since that time, we tell students what we are doing and why (i.e., we explain why this is good for them). As a result, we have more buy-in. However, this "do it because it's good for you" approach only goes so far. We've discovered an additional idea that helps. We now begin the first lab of the first semester by asking students to work in small groups to answer the following question: "What skills and abilities do you feel are most important or most useful to you in being a successful person/citizen/professional? In other words, what types of skills or abilities are you likely to use on a regular basis as a person/citizen/professional?" I give students five minutes to discuss this in small groups. Then I ask each group for one skill or ability they think they will need and record them on the blackboard. This continues until the groups run out of ideas.

The *abilities* they feel are necessary typically include the following:

- Ability to think critically
- Ability to see the big picture and relate what you learn to the real world
- Ability to be flexible, to think on your feet (i.e., Start with a plan but be flexible. If you recognize something is not working, modify or change it.)
- Maintaining a positive attitude and interest in the material (Your attitude communicates more directly than your words.)
- Ability to learn from one's mistakes and a willingness to continue learning
- Having a good base knowledge of the material and techniques

The *skills* they list typically include the following:

- Organizational skills
- Communication and listening skills
- Problem solving skills
- People skills/skills in relating to others

With these skills and abilities listed on the blackboard, I then ask them whether it would be useful to practice developing these skills and abilities during their college years. After they agree, I explain that the labs in this course are designed to give them that practice.

Has this solved all of our problems with student perception of the lab experience? No. It is unlikely that we will ever satisfy all students. Often their past lab experiences get in the way. Most of our students have become used to cookbook-type labs and know how to succeed with them. As a result, some of them don't like the fact that we are "changing the rules." Other students want and expect labs to reinforce lecture material. Still other students don't think that the work they do in their heads is science. To them, doing science means dissection or learning new techniques.

I admit that this strategic change to our lab program means that our students do not get as much exposure to what are often called "hands on" demonstrations of organisms (pickled or live), models of organs, or dissections of specimens. In addition, Research Project labs do not supply weekly topic-for-topic support of the lecture material. On the other hand, our students do learn that:

- Not all problems in life are clearly defined and there will always be some level of uncertainty.
- Most research problems are complex and no single experiment is likely to solve an authentic problem.
- The value of any experiment is determined by how carefully the researcher develops the methodology and controls, and by the quality of the data collection, analysis, and interpretation.
- Research costs both time and money so not all experiments are designed to be definitive; some are "quick and dirty" to provide insight into worthwhile next steps.
- An experiment cannot prove anything – it can only disprove or lend support to an idea. As a result, research experiments are most frequently designed to eliminate possibilities.
- A good experiment usually raises a number of questions that will lead to further experimentation.
- All experiments succeed; however, they may not give us the results we want. As Thomas Edison once said, "I have not failed. I've just found 10,000 ways that don't work."

continued on page 6

Redesigning the Introductory Biology Laboratory Experience
continued from page 5

In addition to all of this, our students learn how to problem solve effectively in groups and how to communicate their understanding in written and oral formats. In my mind, these are major accomplishments.

How Has Lab Redesign Affected Student Learning?

Most of the information I can provide to answer this question is anecdotal. For example, a lecturer who teaches an upper-level immunology course reported she could tell which of her students had taken Biology 151-152 because they could think through experiments and were able to deal with uncertainty. In exit interviews, senior zoology majors have said that they wished more labs on campus provided the opportunity to fail and learn from their failures. In a more definitive study, about six years ago, the University of Wisconsin Pharmacy School conducted a study to determine which entry criteria correlated with their students' success in Pharmacy School. They examined the records of hundreds of students. They looked at GPA, ACT and SAT scores, the students' outside activities, and the courses they took. The only positive correlation with their students' success was whether or not they had taken Biology 151-152.

So what does all this mean? Should everyone stop what they are doing and adopt my labs? If I've learned anything in the past 26 years, I've learned that there is no single right way to do anything when teaching. On the other hand, I have learned some things that I feel can be generalized:

- Before I attempt to teach my students anything, I'd better have a very clear idea of what it is I want them to learn from the process. In other words, I need to know the types of scientific processes, thought processes, and methods I want them to learn. Then I need to develop the lab exercise that will give my students the opportunity to learn them.
- If student learning is the goal, I need to take the focus off the instructor and put it on the student.
- If I want my students to be able to deal with uncertainty, I need to let them experience situations where uncertainty exists and let them deal with it.
- If I want them to be able to learn from their own mistakes, I have to give them that opportunity in a setting where their grade is not affected by the initial mistakes but is determined by what they learned as a result of making and dealing with the mistakes.

I have also learned that real learning is the responsibility of the individual and that the majority of this occurs outside the classroom. However, what goes on in the classroom and what you require of your students should set the stage and give students practice in the learning you want them to achieve. ■

About the Author

Jean Heitz (jgheitz@wisc.edu), a Faculty Associate in Zoology at the University of Wisconsin (Madison), has worked with Botany/Zoology 151-152 since 1978. Her key roles have been in development of active learning activities for discussion sections and open-ended investigations for laboratory sections. Heitz also teaches Botany/Zoology 969, a graduate course in "Teaching College Biology" and has presented workshops at a number of national meetings including the CELS (Coalition for Education in the Life Sciences) IV Conference in 1995 (Strategies for Teaching and Learning in Undergraduate Life Sciences) and the Society for the Study of Evolution Conferences in 1999 (Teaching Evolution to Undergraduates) and in 2000 (Using Bioquest's BIRDD Program to Teach Evolution).

INVESTIGATIVE CASES: COLLABORATIVE INQUIRY IN SCIENCE

Ethel Stanley, Beloit College
Margaret Waterman, Southeast Missouri State University

Building on the strengths of problem-based learning and a commitment to authentic assessment, investigative case-based learning (ICBL) offers real promise as a multifaceted tool in the biology instructor's toolbox. ICBL uses realistic, brief stories to engage students in science. A specific method of analyzing these stories, or cases, turns one of humanity's oldest teaching strategies into a new tool for collaborative science learning.

By using a case such as *The Donor's Dilemma* (Waterman and Stanley, 2005), students learn biology in context as they employ scientific information and methods to investigate and resolve — at least partially — realistic, complex problems. When learning occurs around a specific problem, there is an increased likelihood that this learned material will be better retained and more easily applied in similar situations (Brown et al., 1999, Schmidt, 1983).

Cases Engage Students and Faculty in Collaborative Problem Posing, Problem Solving, and Persuasion

Using investigative cases encourages students to work collaboratively as they identify their prior knowledge and generate questions of interest related to the real, complex situation presented in the case. They may work in teams to explore the case and develop their questions, to conduct related scientific investigations, as well as to prepare and present their findings. Using case