Inquiry-based Learning: Modifying existing lab experiments— Simple changes yield big results

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There is little argument about our need to more effectively teach science in the college classroom. Inquiry-based learning can improve student understanding and practice of the scientific method. Faculty have used inquiry-based learning to successfully renovate courses and entire curricula. These impressive papers describe the new and improved classes and curricula that were designed. The can also be somewhat daunting: massive overhauls are not easily surmountable. Many faculty want to increase student learning by improving their courses, but often don't know how to start. As students develop and hone their inquiry investigation skills throughout their college years, so too do faculty need time to take steps towards the important goal of increasing student learning. Specific frameworks for change need to be readily available. This paper offers a few suggestions on how small changes to laboratory experiments and protocols can create a more inquiry based learning environment. It is our hope that this paper provides faculty with the initial steps needed to start the changes in their own courses and curricula which lead to more student-learning focused classrooms.

How inquiry labs are different

The distinguishing feature of inquiry labs is that they are based on answering a question. Inquiry-based labs are ideal for science classrooms, since questions are the foundation of scientific experiments. Unfortunately, many lab manuals are written to "help" students as much as possible complete the experiment with success. We argue that these "helpful" hints deter students from thinking about the experiment they are conducting. Some thinking-deterrent helpful hints include specifying the function of each reagent in a reaction, forewarning students of what to look for, and providing students with fill-in graphs and tables. Be removing many (but not all) of these hints, we found students were more engaged in the experiment, thought about the importance of each step and were challenged to present their data meaningful ways. What follows are our guideline on how to revise lab manuals to create useful, student-thinking protocols.

How to do it

Step 1. Identify the questions.

Review each of the experiments in your lab manual. What central question(s) can be answered using the protocol provided? Reword the titles of the labs to focus on these main questions. What other, less primary, questions can be answered during the experiment. List these questions at the front of the lab exercise. For example, in our upper division cell biology laboratory, we chose to include a lab exercise in which students isolate spinach pigments to create an absorbance spectrum. The lab exercise was written in a cookbook format and is summarized as follows:

> *Students homogenize spinach tissue and centrifuge it at 600g (10 min) then 10,000g (30 min) to isolate chloroplasts. They add a detergent to the second pellet (containing chloroplasts) and use this solution to determine absorbance spectrum with a spectrophotometer.*

We first identified the main questions that can be answered by the protocol:

1) What is the absorbance spectrum of spinach?
2) Based on the spectrum you identified, what pigments might be present in spinach?

We then identified several questions students could be asked to answer, but were already answered by the lab manual:

3) In which supernatant or pellet were chloroplasts found? How do you know? What does this imply about the size/weight of chloroplasts?
4) In which supernatant or pellet were nuclei found? How do you know? What does this imply about the size/weight of nuclei relative to chloroplasts?
5) What do you predict might be present in the final supernatant? How could you test that prediction?

Step 2. Selective deletion.

What to look for

Many lab manuals provide directions for an experiment, and then direct the students to look for a color change, watch the gas form, or smell the chemical reaction. The manual has revealed the exciting thing about to happen and thus "ruined the end of the movie" for the student regarding this experiment. Inquiry labs avoid revealing the answers to the questions being asked. We have found that students, when direct to do so, make detailed and interesting observations about those very color changes, gas formations, or chemical reaction, without being told what to look for. We have also found that students don't always need to be told the purpose of a reagent or step, but can use their observations to infer its action. For example, students are asked to place a few drops of cytocholasin on a wet mount containing live paramecia and amoeba. They are told that cytocholasin is an actin inhibitor. Most students observe the amoeba stop moving, shrivel up, and appear to die, while the paramecia on that same slide continue to swim about happily. Using their observations students correctly infer that amoba but not paramecia have actin-based cytoskeletons.

How to record data

Choosing the kind of data to record and the style in which to present it is an essential part of the scientific process and can be easily incorporated into the inquiry lab. Consider the following student directions of an enzyme property investigation:

> *Prepare a wet mount of Elodea and purple onion in each of the three conditions: deionized H_2O, 10% NaCl, and 30% NaCl. Observe the sections for 5-10 min and record as many details and observations you can. Use a table, chart, or graph to summarize the data collected.*

When given the option to choose the format in which to present their data, students must think about which format makes the most logical sense for each data set. In early labs, we advise students to use a graph for one type of data presentation and a table for other. In later labs, they discuss with their partners or research teams how to best organize and display this data for easy communication. By not providing an example graph, students must decided which variables belong on which axes. (We have been shocked at some of the graphs proposed by senior level students. That even senior level students have difficulty identifying independent and dependent variables may be an artifact of the fact that students have been provided with fill-in-the blank graphs throughout their previous courses and never had to actually think about which variables in the experiment are affecting other ones.)

Step 3. Selective Addition.

We reviewed the experiments we chose for our cell biology course and asked ourselves which instructions were absolutely essential for ideal data collection and which components could be altered from telling students what will happen to asking students what did happen and why. In our pigment analysis experiment, which involved cellular fractionation, we omitted the phrases “nuclear pellet” and “chloroplast pellet” from the protocol. By opting not to tell students where to find chloroplasts, we developed a mini-experiment within the larger one. Students are directed to perform a quick microscope check of their samples using methyl green and a detergent to determine which sample contains chloroplasts.

Step 4. Reward thinking.

Once you remove the specifics throughout the lab, your students are then free to observe, record and analyze the information they think is important. “What they get” now becomes less important than how they interpret their collected data. Inquiry labs designed using our suggestions can no longer be graded by looking at fill-in tables and charts to determine if students “got the right answer” (and therefore understand the biology), but must now be evaluated for thoughtful and meaningful interpretation. Even if students collect totally unexpected data, they can be rewarded for insightful interpretations. Students will begin to realize that there might not exist one right answer, as many students succeed in the class, even with conflicting data. In our cell biology class, students submit 1) their raw results as they collected them in class, 2) their careful presentation of data, often in the format they chose, and 3) a discussion based on several end-of-experiment questions. Our cell biology labs contain 24 students, and we find the grading significantly more intense than for other courses, but manageable.

Summary

It is important to mention that while our lab protocols direct students to make their own observations and chose the format of data presentation, we do not allow students to wander about the experiment without guidance. Critical thinking on the part of the student begins with a question or a bit of confusion. We nurture questions and modest confusion in our laboratory, where students feel comfortable with their role as true question answerers. In an ideal world, students (and researchers alike) would consistently find expected results. We know this is not true of real research. Similarly, we know that in the college classroom, the labs sometimes simply don’t work out as we expect. The type of lab modifications we are suggesting allow for the data to be as they are, and the grading to be focused on the meaning made from those data. Here we argue that the first steps to making labs more inquiry can simply be small: 1) rephrasing instructions to prevent revealing the outcome and instead keep students looking and observing; and 2) instructing students to review their data and choose the format which best communicates the trends in the data. Additionally, we encourage the instructor to change the grading focus from the right answer to the meaningful interpretations students make of the data they collect.

Getting started:

1. As you wander the room assisting students, avoid telling them what they will or should see. Let them see what they do and evaluate their interpretation.
2. Let them be “wrong.” See them have the experience of grappling with data which may not make biological sense. Let them propose alternatives or experiment that could better explain this “unusual” phenomenon.
3. Reward really insightful interpretations of data even if their data is not as expected.
4. Constantly remind them that science is neither finite nor 100% “right”.
5. Don’t overwhelm freshmen with completely open-inquiry exercises. Recognize that inquiry investigation is a skill students develop throughout their college years. Design exercises that challenge their inquiry skills but don’t drown them in vagueness.