Modifying general chemistry experiments to encourage student interaction and engagement: Small changes that can transform the laboratory experience

Jeffrey J. Bodwin*

Department of Chemistry, Minnesota State University Moorhead, 1104 7th Avenue South, Moorhead, MN 56563

Abstract:

The general chemistry laboratory can be a crucially formative experience for undergraduates interested in science. A well-designed and exciting laboratory experience can foster and appreciation and love of science students at all experience and ability levels. As laboratory instructors encounter common questions and problems, the natural tendency is to modify the written experimental procedure to preemptively answer questions and avoid mis-steps in the lab. This often leads to "cookbook" general chemistry labs that are boring not just for the students but also for the instructor. To address this problem, a number of general chemistry experiments have been re-written. In many cases, the actual experiment has not been changed, only the philosophy used in crafting the experimental procedure. Increased engagement in the laboratory increases retention and recruitment of students in the chemistry program and sciences in general, as well as building a community of learning among the students.

Introduction:

The General Chemistry Laboratory should be one of the strongest recruiting tool for any chemistry department. Students are invited into an engaging and even *dangerous* laboratory to mix exotic substances together and make interesting things happen. Unfortunately, students all too often are discouraged by labs that they consider "hard" or "boring" and are turned away from chemistry and other STEM majors. For most practicing chemists, the thought of chemistry as "boring" is inconceivable. How can a subject that is so ripe with opportunities for experimentation be anything other than thrilling? This disconnect is the root of a great opportunity for chemical educators and students alike. A well-designed and implemented general chemistry laboratory experience can spark a student's interest in the sciences like few other things can. Conversely, a poorly designed or administered experiment can cement the perception of "boring" labs into the student's experience.

General chemistry labs can be designed along the "Spectrum of Inquiry" to be anywhere from free/open inquiry ("here's a bunch of supplies, go explore")[1], to guided inquiry ("here's an interesting experiment, let me ask you a couple leading questions to get you moving")[2,3], to traditionally structured activities ("here's a strict list of instructions, follow it to the letter and good data will result"). The "best" option is largely dependent upon the individual instructor and student, but a well-constructed procedure can provide enough flexibility to allow diverse learning and teaching styles to coexist.

Experiment Selection:

The roster of experiments in a general chemistry class is strongly dependent upon how closely the lab portion is tied to the classroom course content. There are many advantages of lab experiments that closely mirror course content because the lab can be used to reinforce the sometimes abstract concepts presented in the classroom. At the same time, if the lab aspect of a course is being used to promote chemistry and recruit majors, the labs should be more focused on providing an interesting and positive experience and not necessarily wedded to the classroom content too tightly. The first and most critical step in making general chemistry lab experiments engaging to students is to select experiments that inherently provide flexibility in the students' decision-making processes and skill levels.

Some considerations in selecting a roster of experiments for a "good" gen chem sequence include:

1. ***Experiments should have an exciting observable.*** Chemists (and others in STEM fields) often prefer to view and interpret results in graphical form. It's what we've been trained to do, it's very orderly, and it makes sense to us. The typical student has not developed this appreciation of graphical data, therefore if the "goal" of an experiment is to generate a fascinating graph, many students will become distracted. Students want to see interesting colors, precipitates, bubbles and "violent" reactions.
2. ***Experiments should have an easily identified variable.*** If the students will be expected to design portions of the experiment themselves, it can be overwhelming for them to ferret out what to vary. "Easily identified" does not mean trivial, but the variable should not be so obscure that the students will struggle with defining the nature of the experiment before they begin.
3. ***An unknown makes an experiment more interesting.*** Students can certainly perform confirmation/validation experiments, but there is an added level of interpretation required when an unknown is involved. The "real world" is full of unknowns; including an unknown in the lab allows students to make more facile connections between theory and application.

Setting a Roster:

One opportunity in experimental design is in the overall roster of experiments for the course. A well-ordered roster continually reinforces concepts and builds upon previous experience. A poorly ordered roster seems like a random scattering of experiments intended to do nothing much more than keep the students busy throughout the semester. In examining our roster of experiments in 2004/2005, there is some continuation and a logic to the progression, but there was room for improvement. Over the course of a few years, a new roster was developed for both Gen Chem I and II in which a consistent thread ran through at least part of the semester. In the Gen Chem I roster, there is series of experiments that all address ways in which the stoichiometry of a reaction can be determined ("The Reaction of Aluminum with a Strong Acid", "Using Conductivity to Explore a Chemical Reaction" and "Determining the Stoichiometry of a Reaction by Continuous Variation"). Although these experiments could all be used to explore separate concepts (gas laws, molarity, net-ionic reactions, enthalpy, etc), placing them consecutively in the schedule gives students a better appreciation of the "big picture" in stoichiometry.

Similarly, in the second semester a series of experiments are used to determine the concentration of reactants and products in a system at equilibrium ("Calcium Iodate", "Iron(II) Nitrate and Potassium Thiocyanate" and "Acetic Acid in Water"). Again, these experiments could be though of as independently looking at solubility, complex ion formation, and an introduction to acid/base chemistry, but relating them to one another helps students appreciate the underlying theory, equilibrium.

"Freeing up" inquiry

The experimental procedure was modified for this experiment without actually changing the experiment itself. In the "old" procedure, students were told what to use, what to vary, and the variable was assigned by the instructor. In the "new" procedure, students are directed to perform a standard reaction and then told to design additional experiments to explore the relationship between the amount of reactants and the volume of gas produced. Leading questions are also included in the experiment, set off as bullet points so students will pause and consider them at relevant points in the experiment. One of the unexpected outcomes of this re-write was that the students "discovered" a variable that we had not considered, the volume of acid used in the experiment.

*Note: In the "old" schedule, this experiment followed an experiment using the same gas collecting apparatus; the figure shown in the "new" procedure was part of the previous experiment. In the "new" schedule, this is the first experiment the students perform in their first gen chem lab.

Data Tables and Pre-Labs:

This experiment has seen significant changes in the procedure, but again, there is very little change in the actual experiment.

One of the most obvious changes is the addition of Pre-Lab Exercises. These were added to the second semester Gen Chem labs to force students to look at the experimental procedure and review basic calculations *before* they walk into lab each week. These Pre-Labs are typically due the day before lab and are graded and returned at the beginning of lab.

Another notable change is the elimination of data tables in the experimental procedure. This was done partially because the nature of the experiment has changed to require student-designed procedure and while their designed experiment was usually quite predictable, the lack of pre-formatted tables encourages students to think about their data more independently. Removal of the tables also encourages proper use of the lab notebooks that are required in our Gen Chem labs, rather than just jotting numbers down in the lab manual.

Two significant experimental modifications are the removal of a qualitative section that ***always*** lead students to incorrect conclusions, and a more clearly distinct determination of the Beer's Law constant. As with all of our revised experiments, this procedure also strives to make students think more critically about error in their experiments including a quantitative appreciation of their error.

The Next Steps:

Current revisions have significantly improved the quality of our students' experience in the General Chemistry Lab sequence, but additional steps are already being taken to modify the courses. The majority of the changes that have been made up to this point are changes in the written procedures for our current roster of experiments. For a variety of pedagogical and other reason, it will be necessary over the next few months to radically redesign our entire lab sequence. This will likely involve elimination of some of our "old standby" experiments and implementation of a number of new experiments. The advantage of doing this type of redesign at this point is that the lesson we have learned will lead us to select new experiments much more intelligently. This redesign will also include a formal assessment plan of the General Chemistry labs, a further step toward intelligently structuring this critical undergraduate experience. By *starting* with this model of engagement rather than adjusting our experiments to it, we will be able to develop a more cohesive and consistent laboratory experience for our students. This will lead not only to active *learning* in the laboratory, but active *teaching* as well.

References/Resources:

There are many good inquiry-based lab manuals available, a quick search of Amazon.com results in a surprising number of hits. A few that I have found specifically helpful are:

1. Lechtanski, Valerie Luwig "Inquiry-Based Experiments in Chemistry" ACS/Oxford University Press, 2000.
2. Kerner, Nancy Konigsberg; Lamda, Ram S. "Guided Inquiry Experiments for General Chemistry: Practical Problems and Applications" John Wiley & Sons, 2008
3. Abraham, Michael R.; Pavelich, Michael J. "Inquiries into Chemistry" Waveland Press, 1999

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Minnesota State University Moorhead Department of Chemistry