"Who Has the Same Substance that I Have?"

A Blueprint for Collaborative Learning Activities

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As we restructured the undergraduate chemistry curriculum at The University of Michigan, we also took a fresh look at the nature of the laboratory experiences that would accompany the new courses (*1, 2*). In the new sequence, we have many students who take their first college chemistry laboratory course along with *Structure and Reactivity*, our introductory course based primarily in a mechanistic organic chemistry context (*3*). In creating these courses, we wanted to capture the essence of a research experience: the design, implementation, and evaluation of an experiment with an uncertain outcome. This plan allows students in an introductory course to construct their own understanding of a solution to a problem without requiring instructors to direct 2500 research projects a year with very inexperienced individuals (an intimidating notion!).

We devised the following criteria as guideposts for our thinking about the first-term laboratory course.

Make Problems Comprehensible. About 50% of our students have not had a high school laboratory course, so we cannot count on much prior knowledge of lab work. If student learning is to be subject-centered and based on prior experience, then the tasks must be comprehensible to the novice. One common complaint from students in traditional laboratories is that they simply are following directions and not engaged in activities with any intrinsic meaning to them.

Embrace Imperfection and Promote Improvement. We are committed to let experience lead, whether it is observing solubility phenomena or recording an infrared spectrum. We want students to experience phenomena and to have a chance to develop their abilities through repeated practice. An hour of careful discussion and preparation for what is to be observed is a symptom of an upcoming laboratory activity that a student is not yet ready for, or for which an instructor is taking too much preemptive responsibility. Students should not be expected to master an unfamiliar activity the first time that they do the experiment and be threatened with the disincentive of a grading penalty if it is not done correctly.

Use Techniques as Tools to Solve Problems. The "puzzle" approach (*4*) to lab activities is better than locked-step validation laboratory exercises. We also wanted to emphasize the variety of techniques that chemists use routinely in order to collect information about substances. To these ends, we see no purpose in any discussion of "cookbook versus discovery" because this is a false dichotomy. Cookbook and discovery are not opposites on a linear spectrum; instead, they are related to each other on intersecting axes. Chemists generally begin with known procedures and strategies (cookbook) in order to make discoveries.

Integrate Needs for Quantitative and Qualitative Laboratory Tasks. The traditional content of an introductory organic chemistry laboratory course does not address the fundamental quantitative techniques that are an important part of laboratory work because the organic course presupposes at least one general chemistry laboratory. We are increasingly more explicit in addressing analytical chemistry topics in the *Structure and Reactivity* laboratory course.

Promote Collaborative Laboratory Work. Whereas cooperative learning strategies tend to create environments for group responsibility in task management (*5*), the process of collaboration maintains individual responsibility within any group effort. We propose that a collaborative learning task promotes individual responsibility within the context of a group task that is solvable only by the contribution of each participant.

Collaborative Identification of Unknown Materials

Whether by consulting a reference text or using our recall of physical, chemical, and spectroscopic properties, we compare the data we collect in lab with some set of standards in order to answer the question "What is this?" Rather than provide inexperienced students with an explicit algorithm for making an absolute identification of a substance, we have taken the core of this activity and created a problem in relative identification that is at once a simple, honest inquiry and a vehicle for developing technical and communication skills.

"Who has the same solid that I have?"

On the second week of college, students in each section of a 22-student *Structure and Reactivity* laboratory course are presented with a box of 30 vials, numbered in sequence, that all contain a few grams of a finely powdered white solid. In addition to referencing parts of a techniques manual where melting points, solubility tests, thin-layer chromatography, and infrared spectroscopy are discussed, students are provided with the following information (*6*).

> Most scientists collaborate and cooperate with each other in making scientific discoveries. Modern science involves a lot of team work. Many times, also, the same discovery is made at the same time by different scientists in different parts of the world. They then have to exchange data and samples of chemicals or biological specimens to prove that they are, indeed, dealing with the same substances.
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> In this experiment you will be attempting to solve a puzzle together with your classmates while you learn basic techniques used for the analysis and identification of organic compounds, as well as getting to know your classmates. We hope that this will be the beginning of a habit of working together in learning your lecture material as well as in the laboratory.
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> The puzzle is simple. Chemists define substances on the basis of an accumulation of observable properties. For example, when we say "water," we mean "that clear, colorless, odorless liquid with a boiling point of 100 °C, freezing point of 0 °C, a density of 1 g/mL that dissolves substances like salt, that upon electrolysis gives a mixture of hydrogen and oxygen gases in a

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definite ratio". . . and so forth. Using our molecular model of matter, itself a result of the collective imagination of chemists, we say that "water" is "H_2O," and we mean to indicate that whole accumulation of information behind that simple symbol. Thus, a fundamentally important skill is to determine accurately and to compare the physical properties of substances.

You will obtain a sample of an organic solid. You will determine properties such as its melting point, its infrared spectrum, and how it moves on a thin-layer chromatography plate in one or more solvent systems using one or more visualization techniques. **Your goal is to find the other students in class who have the same compound that you have.**

Comparisons of different samples may be made in a number of ways:

1. by spotting the samples side by side and co-spotting on a TLC plate;
2. by comparing solubility and appearance of the samples; and
3. by taking melting points and "mixed melting points," a melting point of an intimate mixture of the two compounds.

If the two compounds are identical, the mixture will not melt any lower than the individual samples do. If the compounds are different, one will serve as an impurity in the other. Impure substances melt at lower temperatures than pure samples do.

Your laboratory section should work out a method for sharing and reporting your sets of individual data. Once you have identified yourselves with a particular compound, the group should affirm the predictions about who has the same substance and also confirm that there are no others in your lab room who belong with the group.

We provide 10 sets of triplicates in the solid samples, which generally include a variety of aromatic hydrocarbons, ketones, and carboxylic acids. The most important practical aspect of setting up this laboratory is to ensure that the identification is based on the experimental data that are collected by the students. The activity is vulnerable to dishonesty in a number of ways, so the following caveats should be kept in mind:

- Do not use coding schemes that can be decoded.
- Do not give out lists and samples of possible substances too early.
- Do not give the lab instructor the master list (alternatively, hide your list).
- Do not permit colored substances.
- Do not leave solids unpowdered.

By using melting points (and mixed melting points), thin-layer chromatography (with co-spotting), and solubility tests (5% aqueous hydrochloric acid, 5% aqueous sodium bicarbonate, acetone, and water) a class can group themselves easily and double check their observations within a few hours. One of the questions that spontaneously arises every term is, "What constitutes a valid comparison?" The melting point data only group together rather than occur with exact duplication, so we always hear a version of the following: "Is 156–157 °C on my thermometer the same as 152–155 °C on yours?" A very productive iterative cycle occurs as the need for reproducibility causes students to revise their original reports in the context of new information. The experimental techniques are seen clearly as tools by which data are collected and from which a simple question can be answered.

Another unique aspect of organizing an activity around the "Who has the same ssubstance that I have?" question is that collaboration requires communication. As a group, students in a lab section must establish procedural norms for collecting data, such as what proportions to use for solubility tests and for reporting and exchanging data that are required in order to solve the problem. On any afternoon, we can have eight sections of the *Structure and Reactivity* laboratory course operating with eight different sets of procedural standards and communication strategies. Finally, this is a *collaborative learning task* , as described above. After the entire group has established its common experimental procedures, individual students are responsible for collecting data from their own substance. As the information flows from individuals to the whole classroom community, smaller collaborations occur spontaneouly as subgroups begin to gather around a common substance, along with the need for building consensus about the properties of the substance they suspect they share.

For the next laboratory period, the instructions are geared for taking the relative identification to an absolute one.

Once you have identified yourself as part of a group of students who all have the same substance, you should deal with the identification of that material. Consult a list of possible substances that your TA has in order to begin to make this decision. Samples of these compounds are available for performing TLC, melting point, and solubility comparisons between your unknown compound and the possible knowns. You also should record infrared spectra of your solids in order to make a judgment about what kind of functional group classification your compound falls into.

When you think you have an idea about what compound you have, you should also select an appropriate chemical derivatization method for that functional group and prepare it. You can use both your unknowns and the known compounds (for practice) in this procedure.

The collaborative identification blueprint works for developing a variety of laboratory skills.

"Who has the same liquid that I have?"

In this activity, we provide students with about 5 mL of a clear, colorless liquid (usually ketones, esters, and hydrocarbons). The techniques we use are thin-layer chromatography, gas chromatography, solubility tests, infrared spectroscopy, and boiling point determination.

"Who has the same solution that I have?"

There are many ways to conceive of applying this question. In practice, we have not used this with our *Structure and Reactivity* students, but we have tried three versions of this question in two other venues. First, we suggested that a local high school instructor[2] use solutions of different concentrations of acetic acid (from 5–15% by weight) as a way to introduce titration to the class. Students in our preservice elementary teachers course did the other two versions. In one activity, we prepared different concentrations of sodium chloride solutions that the students investigated by relative densities: solving the logic problem of relative layering (after adding a little food coloring to distinguish the samples). In the other, we used different concentrations of chlorine bleach and investigated them by measuring the degree of the exothermic reaction produced when an aliquot of acetone was added (7).

"Who has the same metal that I have?"

This is also an activity we have used with our preservice teachers. A simple modification of a traditional density measurement lab, we started with a number of different irregularly shaped pieces of metal in many sizes (from the scrap box in the machine shop) and covered them with a black enamel paint. We also pasted numbers on each piece of metal. The students used balances, rulers, graduated cylinders and overflow tanks to make mass and volume measurements. After the students generated a list of densities based on their measurements, we then gave them

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other pieces of unpainted metals as "unknowns" for them to identify according to their "standards."

Extending Collaborative Activities to Other Courses, Other Grade Levels, and Other Subjects.

As described above, we have used collaborative activities in many places in our curriculum. In addition to the preservice teachers course and the high school class, we have also used "Who has the same solid that I have?" for five years as part of outreach programs for middle school and high school students who visit our department for either a day or a week. Precollege students, using only solubility observations and melting point determination, routinely solve the solids problem in about an hour. For groups of very young students, we have simply placed common objects inside of a plastic film canister and had them answer the relative identification question based on comparisons of sound and touch. An imaginative adaptation of this idea was done by one of our colleagues in the mathematics department.[3] At the beginning of an introductory math class, every student in the class was handed a slip of paper on which a set of four numbers was written. These numbers were sequential portions from a variety of different series. the student's task: Identify who has numbers from the same series as yours.

Differential discriminations are made by individuals in every discipline, of course. Some of our colleagues in other departments have reported their own adaptations of this idea to us: in art history ("who has a painting from the same period that I have?"); in psychology ("who has the same personality classification that I have?", and in journalism ("who has the paragraphs structured the same way I have?").

Conclusion

The collaborative identification of substances is a simple blueprint for any activity where related samples can be investigated by an appropriate technique. This activity gives a way for instructors to demonstrate the relationship between collecting experimental data and drawing conclusions, as well as how to make and evaluate comparisons. Students also are required to create procedural standards and to communicate within the context of a scientific problem in a natural and need-based manner. Collaborative identification is an honest inquiry that encourages students to combine technical and social skills, a goal of many reform-minded educators. We look forward to seeing how others will adapt this idea to new classroom situations.

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