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Modifying a Lab Activity Into an Inquiry Investigation

THE ROLE OF THE LABORATORY IN SCIENCE

Despite the recent concern over science instruction, achievement levels, and the rising costs of education, doing laboratory work in high school science classes has a rich presence and history (DeBoer, 1991). As early as the end of the 19th century, Thomas Huxley embraced the importance of the laboratory experience. As Huxley (1899) put it (with apologies for the gender reference),

> In teaching him botany, he must handle the plants and dissect the flowers for himself: in teaching him physics and chemistry, you must not be solicitous to fill him with information, but you must be careful that what he learns he knows of his own knowledge. Don't be satisfied with telling him that a magnet attracts iron. Let him see that it does; let him feel the pull of the one upon the other for himself. (p. 127)

Today, however, with the cost of new technical and scientific equipment, the additional time needed to schedule labs, and the additional space needed for science labs, high school teachers are often called upon to defend the need for the laboratory experience. A majority of the students in your class may not aspire to become professional (career) scientists, so, in times of shrinking economies, many teachers are faced with the following questions: (a) Why should high schools provide students with laboratory-based science courses? (b) What role does the hands-on laboratory experience play in learning science concepts? Numerous arguments support laboratory-based instruction:

1. Laboratory experiences develop manipulative skills such as handling equipment, reinforcing hand-eye coordination, and practicing sensorimotor skills. By manipulating scientific equipment and materials, students learn to manage technical skills such as massing objects, using a microscope, staining samples on slides, techniques, and performing titrations.
2. Laboratory experiences reinforce science process skills such as observing, classifying, measuring, inferring, experimenting, and manipulating variables.
3. Laboratory experiences reinforce the use of the scientific method, by which students formulate hypotheses, control variables, design procedures, collect data, and analyze results.
4. Laboratory experiences enhance communication skills such as following directions, reading, speaking, listening, and writing reports.
5. Laboratory experiences develop inquiry and investigation skills.
6. Laboratory experiences reinforce organizational skills as well as group responsibility and collaboration.
7. Laboratory experiences reinforce concepts from the lecture/discussion portion of the class and extend learning to the problem-solving level.
8. Laboratory experiences support cognitive skills, critical thinking, problem solving, and higher-order thinking skills such as analysis, synthesis, and evaluation.
9. Laboratory experiences integrate science, technology, and mathematics.
10. Laboratory experiences develop habits of mind and scientific attitudes such as curiosity, risk taking, precision, and confidence.

Most important, the laboratory links the concepts being studied with real-world applications. According to the National Research Council,

> Designing and conducting a scientific investigation requires introduction to the major concepts in the area being investigated, proper equipment, safety precautions, assistance with methodological problems, recommendations for use of technologies, clarification of ideas that guide the inquiry, and scientific knowledge obtained from sources other than the actual investigation. The investigation may also require student clarification of the question, method, controls, and variables; student organization and display of data; student revision of methods and explanations; and a public presentation of the results with a critical response from peers. Regardless of the scientific investigation performed, students must use evidence, apply logic, and construct an argument for their proposed explanations. (NRC, 2000a, p. 166)

In the end, the laboratory experience is a multifarious and circuitous process. To become competent in experimentation and investigation, students need to understand the problem being posed, the concept on which the experiment is predicated, and the language in which the context of the procedure is based. When we talk about the *language of the procedure,* we refer to the process by which inquiry occurs. That frequently is referred to as the scientific method. Although inquiry seldom follows the step-by-step procedure prescribed by the regimen of the scientific method, it does provide a systematic and sequential framework for understanding the complexity of an investigation.

The following 13 steps describe the typical processes characteristic of a scientific investigation:

1. State the problem or question to be solved.
2. Identify all possible variables or factors that could influence the outcome of the investigation.
3. Construct a statement or hypothesis to test.
4. Identify the manipulating variable (independent), responding (dependent) variable, and controlled variables.
5. Design the procedure or steps to test the hypothesis.
6. Determine the supplies, material, and equipment necessary to perform the investigation.
7. Carry out the investigation and acquire data.
8. Record and organize data on a table or a chart.
9. Construct a graph, label the axes, and provide a title for the graph.
10. Describe the relationship between the manipulating (independent) variable and the responding (dependent) variable.
11. Draw a conclusion to determine the validity of the hypothesis.
12. Prepare a written report, PowerPoint presentation, or trifold poster of the data and conclusions.
13. Communicate your findings.

NEW APPROACHES TO TRADITIONAL LABS

Many teachers prefer doing traditional labs and prescribed activities with their students. They are often more comfortable with this type of lesson because it is the way they were taught. They may say, "I like that particular lab. I've been doing it for years," or "I do it because it's in the textbook." The purpose of this section is to provide the reader with suggestions on making traditional labs more inquiry-oriented. That is not to say that traditional labs don't have a purpose or place in the high school science curriculum. At times, such as the beginning of the school year, or when time is at a critical shortage, or when students have not had prior experience in designing labs on their own, or even when safety is an important issue, it may be more appropriate to provide students with a directed, hands-on laboratory experience.

Traditional labs are most often found at the end of the chapter in the course textbook. The purpose of the lab may be to verify or confirm through a hands-on experience a concept previously introduced in the chapter. Commonly referred as *cookbook* *labs*, these labs usually provide the student with the question to be investigated, the materials to be used, a step-by-step procedure, safety precautions, a guide on how to organize the data in a table or a chart, and leading questions to analyze the data. When students do cookbook labs, there is a degree of certainty and predictability in the conclusions. The amount of time it takes to reach an outcome is also unerringly anticipated. And the opportunity for individual dissimilarity is substantially curbed.

Writing for *The Science Teacher*, Colburn (1996) stated that "you don't have to abandon these [cookbook] activities to make your teaching more inquiry-based. There is a middle ground between activities that are teacher directed and those that are almost totally student centered" (p. 10). The teacher's understanding of instruction plays a key role in modifying labs (Bernstein, 2003; Clark, Clough, & Berg, 2000; Clough & Clark, 1994; Colburn, 1996; Colburn & Clough, 1997; Shiland, 1999; Volkmann & Abell, 2003). By making minor changes to the format and structure of the lab, teachers can provide a transition into inquiry-based learning, with more empowerment being granted to the students and with students developing more responsibility for their own learning.

As teachers modify their existing cookbook labs to create more open-ended labs, they encourage inquiry in the classroom. Changing a traditional textbook activity into an inquiry-based investigation can be relatively easy. It does not mean you have to give up favorite science activities you are already using. Shiland (1999) suggests that meaningful learning does not occur when students merely follow procedures identified in a prescribed activity. When you realize that cookbook labs and prescribed activities do not meet the instructional goals you have set for your students or that you are ready to adapt some of your (or your textbook's) existing activities, consider modifying your activities by referring to the Invitation to Inquiry Grid from Chapter 5 (Figure 5.1).

The following recommendations will assist high school science teachers in modifying their favorite "time-honored" labs that conform to the scientific method and will help teachers move from structured activities to teacher-initiated and student-initiated inquiries. These suggestions are presented in order, starting from the beginning of the lab and working toward the end.

Do a Prelab Assessment

Before actually starting the laboratory, constructivist and inquiry teachers want to know students' prior understandings about the topic or concept being investigated. In other words, you want to gauge before you engage! By assessing prior knowledge, you may discover many naive conceptions and misconceptions. Determining students' points of reference for a lab will allow the inquiry-based teacher to make modifications in the way the lab is presented so as to fit the students' past experiences. Because it is not unlikely that a high school chemistry class will have a mixed proficiency when using scientific equipment, knowing individual students' prior knowledge will also allow the teacher to make individual accommodations for a diversity of students' skills and abilities.

Do the Lab First

As previously mentioned, in most textbooks the lab is found near the end of the chapter. Resist the notion that you always need an understanding of certain concepts or facts to do the lab, and do the lab first. Begin by choosing an exploration or a lab that is nonthreatening and highly motivating. The lab should also require little prior knowledge as a prerequisite for its completion. Think, in advance, of the kinds of prompts and questions you will need to pose to students to lead them in the right direction. Use the results of the lab to stir excitement about the topic you are now about to present. Refer to the lab throughout your unit as a previous experience. The following is one example of a general chemistry lab that needs minimal prior knowledge about percent composition, solubility, mass, mixtures, evaporation, and filtration to complete the investigation. Most high school chemistry students have enough prior experience from their middle school science courses to complete the problem with little or no assistance from the teacher. The laboratory is called "Sugar and Sand."

The Objectives of the Laboratory:

1. To develop the ability to analyze and solve problems
2. To plan and perform a laboratory procedure to solve a problem
3. To select materials and equipment to carry out an investigation

The Task:

Given a 100-gram sample of a mixture of sugar and sand, the student will plan and perform a procedure that will determine the percent composition of the mass of the sugar and sand mixture.

The Problem:

What is the percentage of sugar and sand in a mixture?

The Situation:

You are a laboratory technician and are presented with the problem of determining the relative amounts of two compounds in a mixture. You are given a 100-gram sample of a mixture of sand and sugar. Design a procedure to determine the percentage of the mass of each of the two compounds in the sample. Once you have planned your procedure, carry out the procedure and report your findings.

Materials and Equipment:

The following materials and equipment are available for students. Additional materials, not needed to complete the problem, may be added as distracters:

- Triple-beam balance
- Filter paper
- Funnel
- Beaker
- Heat source or drying oven
- Evaporating dish

- Ring stand
- Stirring rods
- Water

At the conclusion of this lab, the teacher can give a presentation on percent composition, solubility, mass, mixtures, evaporation, and filtration. During the presentation, as the teacher introduces new concepts, he or she can refer back to the lab that the students performed and discuss their results.

Revise the Question Section

If the lab provides a starter question to answer, as it usually does, remove it. Start by demonstrating a discrepant event for students to observe. Allow the students to think of questions to investigate from the discrepancy. Provide prompts and explorations to lead students to the original question of the activity or lab. Allowing students to come up with the question or problem makes the investigation more personal and meaningful to them. This makes the activity more like a student-initiated inquiry. When designing a lesson around the 5E Learning Cycle, the Engagement or the Exploration stages can provide an excellent starting point for inquiry-based investigations. Inquiry can again be reintroduced during the Extension or Elaboration stage. Several excellent resources for demonstrations and discrepant events are listed in the back of the book.

Revise the Materials Section

If the lab provides a list of needed supplies and equipment, there are several alternatives to consider. In the beginning, cut the list of needed supplies and equipment into single strips or write them on small strips of paper (1 × 5 inches). Include several unnecessary items in the set. Students will determine which supplies and equipment are necessary and which are not. Later, you can provide a partial list of the supplies and equipment, perhaps four of the eight items. Students will write in the missing supplies and equipment. Eventually, students will list *all* the supplies and equipment for the materials section.

Remove the Safety Rules

Whether or not students design their own experimental procedures, they can always be encouraged to write the safety rules and guidelines for the lab. Consider having students align each safety rule to a particular step in the procedure. For example, if the lab calls for heating a substance in an open test tube, the students would write a safety rule connected to that specific step. You may find that students are more likely to follow a safety procedure if they suggest it. Safety rules that are imposed are often opposed.

Revise the Procedure Section

This is a key area in modifying traditional labs. If the lab provides a step-by-step list of procedures, there are several alternatives to consider to make it more student-centered. In the beginning, cut the list of the individual steps in the procedure into single strips or write the steps of a lab on small strips of paper (1 × 5 inches). Give a set to each group of students. Have the students read the steps and put them into a logical and sequential order. After a few labs, provide additional, unnecessary steps in the set. Students will determine which steps are necessary and which are not. Later, you can provide a partial list of the steps, say four of the eight steps. Students will write in the missing procedures and construct the lab. Eventually, students will design *all* the steps for the procedure section. Allow students to "brainstorm" how they would design an experiment or investigation to answer the original question, prediction, or hypothesis. This makes the activity more like a teacher-initiated inquiry.

Add Procedural Errors

Using the "Find My Mistakes" approach, Galus (2000) provides an incorrect experimental procedure and has students find the errors. According to Galus (2000), "Although students [are] not sure of the correct laboratory experiment necessary to test something that interests them, they [are] experts at pointing out someone else's mistakes. [Thus] students become experts in critiquing the process and determining the right way to complete an inquiry-based laboratory exercise" (pp. 30–31).

Take Away the Data Table or Chart

Another suggestion involves the data tables and charts. If the lab provides a predetermined data table or graph, remove it. Encourage the students to determine how they will collect and organize the data. Have students share their results in small groups and compare their findings. Students will have to construct meaning to the data in order to organize and record it into a table. If they cannot formulate a data table, they may not understand the significance and correlation of the data to the activity or may not have mastered strategies for organizing data. By designing their own charts and data tables, students demonstrate and reinforce their understanding of the difference between the dependent and the independent variables.

Redesign the Results Section

Traditional textbook labs often provide space for brief, one- or two-sentence summaries. As one means of improving students' observation and communication skills, consider replacing use of these questions with students writing a detailed, narrative description of what they observed in the investigation. In the results section, students can describe how their observations relate to the hypothesis and reflect on the significance of the observation phase. Students then can go on to predict what would happen if they changed one of the variables in the investigation.

Add "Going Further" Questions to the End of the Lab

By adding analysis and "going further" questions to the end of the lab, you extend the experience and use the activity as a springboard to inquiry. Allow students to raise "What if . . ." and "I wonder . . ." questions to investigate. Consider testing other variables in the original experiment. Encourage students to test different variables with an experiment. If, for example, a class of biology students were investigating how the amount of sunlight affected the growth rate of a plant, the teacher could prepare questions as prompts to start students thinking about other variables that affect the growing rate of a plant. Individual groups of students could design experiments to determine the effect of fertilizer on the growing rate. Others could test the amount of water or the type of soil on growing conditions.

Look at the questions at the end of your labs and the ones provided in the textbook. If the questions provide opportunities for students to analyze and evaluate the lab thoughtfully, but not through additional inquiries, consider adding questions that engage students in more investigations. With "going further" questions, students use the *initiating* or *starter* investigation to guide their design to plan the steps, what information/data to record, how to organize the data on a chart, how to graph the data, and how to analyze the results. Although we are tempted to provide these "end of the lab" questions orally through a class discussion to save time, teachers will find that when students actually do the "going further" investigations, the concepts are solidified and students have opportunities to explore and extend their understandings.

THE HYDRATE LAB

The following lab is an example of how one high school chemistry teacher, Tom Mueller, took a traditional copper sulfate hydrate lab and revised it using the 5E Learning Cycle, making it more inquiry-based. The original lab provided the question to be studied, the materials to be used, the steps in the procedure, and a predetermined table to organize the data.

For the hydrate lab during the previous year, Tom's students completed a prelab assessment. As part of the assessment, students observed crystals of copper (II) sulfate pentahydrate and recorded their observations. After giving the class the prelab assessment, Tom determined that many of the students had difficulty believing that small blue crystals of copper sulfate could have any water content. Because he knew the phenomenon of hydration was an essential concept of the chemistry standards and curriculum, he decided this year to revise his approach to the lab based on the students' prior conceptions. He modified the lab through an extended 5E Learning Cycle. The following is a synopsis of Tom's revision.

Engagement

Anticipating that students would have difficulty understanding the notion that the blue crystals contained water, Tom showed the class an apple and posed the question, "Does this apple contain any water?" Taking a big bite out of the apple and squirting juice in all directions, he continued, "How do you know?"

Tracy answered by saying, "Sure, the apple is juicy, and some of that juice is made up of water."

"That's a great start," Tom suggested. "Now, how could you determine the percentage of water in the apple?"

Jason responded by saying, "You would have to weigh the apple to determine its mass. Then heat it to drive off all the water inside the apple and reweigh the apple to calculate the percentage of water."

After a bit more discussion, Tom pulled a dehydrated apple from his desk, held it up for the class to see, and gave the students its mass in grams before and after heating. Two minutes later, the students had calculated the percentage of water in the apple to be 65%.

Exploration

Now that the students had a concrete understanding of the percentage of water in an apple, it was time to move on to various other fruits. On his desk, Tom then placed a bowl containing oranges, grapes, plums, bananas, cherries, and a few exotic-looking fruits. "For homework tonight," Tom explained, "your assignment is to take one of these fruits and heat it gently in the oven at home to drive off all the water. Tomorrow in class, you will mass the fruit and determine the percentage of water in it." He had each student come up and choose a fruit. The students were instructed to mass their sample and place it in a clear plastic ziplock bag before the end of the class. The next day, they would remass their shriveled sample and determine the percentage of water.

Explanation

The following day, Tom presented a short lecture on the concept of hydration while students took notes. Later, he had the students remass their samples and share their calculations on the percentage of water. Jessica offered to share her calculations for the banana with the class:

Mass of the banana before heating = 110 grams

Mass of the banana after heating = 52 grams

Mass of water driven off = 58 grams

Percentage of water = 53%

Other students posted their fruits and percentages. The samples were then placed in sequential order from the greatest to the least amount of water. Some students then shared comments about using fruit hydrators and the benefits of freeze-dried fruits when hiking and camping.

Extension and Elaboration

With the fruit hydration example in mind, students now were given the task of designing a lab to determine the percentage of water in copper (II) sulfate pentahydrate crystals. By applying the formula from the previous activity, students worked in groups to develop a procedure and experiment for determining the percentage of water in copper (II) sulfate pentahydrate. They also used the example from the fruit investigation to design their own charts and tables to organize the data.

Many students decided to use the following materials:

- A sample of copper (II) sulfate pentahydrate crystals
- A heat source
- A test tube

- A test-tube holder
- A ring stand
- An electronic balance

The groups also had to record their own safety rules for the lab. With lots of ideas flying about, one group brainstormed the idea of using an evaporating dish versus heating the sample in a test tube. In the end, all the groups were able to design and carry out the experiment. At the conclusion of the data analysis, the percentage of error among the student groups was discussed.

Evaluation

As an evaluation of the hydrate concept, some students were given samples of other hydrates to calculate the percentage of water. Other students were given two samples and had to determine which sample was the hydrate and which is the non-hydrate. In either case, students had to use the knowledge and skills from the original investigation and apply it to a new performance task.

This is just one example of how teachers can revise a traditional lab and make it more inquiry-oriented and student-centered. As science teachers decide to use more inquiry-based investigations, there is no reason to discard the time-honored labs they have done over the years. Consider modifying aspects of the lab, and turn over more decision making and responsibility to the students. By following the suggestion made earlier in the chapter, you will find the transition into inquiry to be a smooth and evolving process.