Reforming cookbook labs

The majority of ancillary materials provided with any textbook includes a large quantity of labs that have step-by-step instructions. Although it is important in science for students to learn how to follow directions, offering only cookbook labs limits students' access to exploration. A worthwhile goal of a science teacher is to allow students to think and behave like scientists rather than to solely learn or replicate what other scientists have already done. "Recipe-like activities often short circuit opportunities to stimulate thinking by students"(Germann, Haskins, and Auls 1996). Students often do not see the big concept that a cookbook lab is trying to convey. Students read each step discretely and do not connect the steps to see the bigger intention of the laboratory experience. Students have difficulty constructing meaning from cookbook labs, but inquiry-based labs require ongoing intellectual engagement of the students. Cookbook labs do not give the students an authentic sense of the nature of science (Cox 1972). If inquiry-based learning provides such valuable opportunities, why don't more teachers provide for open-ended exploration?

Management tends to be the biggest issue for classroom teachers when it comes to inquiry-based labs. The amount and types of required materials available are limiting factors. The possibility of a large number of student-generated procedures introduces an unknown factor that many teachers are not comfortable with. Teachers may not have direct access to laboratory materials during the class, which introduces a lag time between the students' request for materials and the delivery of materials to the lab.

Deconstructing cookbook labs to require the students to be more thoughtful could break down perceived teacher barriers to inquiry learning. Simple steps that remove or disrupt the direct transfer of step-by-step procedures in cookbook labs make students think more critically about their process. Through trials in my middle school physical science classes, my high school physics classes, and my high school Earth science classes, I have developed 11 different ways of altering cookbook labs so that students understand the intention of the procedure. The altered labs do not fully achieve the status of inquiry lab, but they are a step toward allowing more open-ended discovery. The changes to the labs described below progress from most structured to least structured. From my experience of sharing these techniques at national teacher conferences, I believe that teachers who reform cookbook labs are more likely to adopt inquiry-based labs in the future. Reforming cookbook labs into critical-thinking labs could be the intermediate step that helps teachers reach the goal of providing inquiry-based opportunities for their students.

Students take on roles

The easiest adaptation that can be done to cookbook labs is assigning roles to each student. Students use the step-by-step procedure to accomplish the lab goals, but they become interdependent on each other because the tasks required to complete the lab are split up among the group members. Each student in a group of four takes on the role of Principal Investigator, Reporter, Recorder, or Materials Manager. The Principal Investigator is responsible for overseeing the lab, for keeping all members on task, and for assuring that all members participate equally. The Reporter is

FIGURE 1 **Mixed-up procedure for determining the density of an unknown liquid**

Place these steps in their proper order for determining the density of an unknown liquid.

- Plot a graph of your trials using volume as an independent variable.
- Pour a reasonable quantity of the unknown liquid in your graduated cylinder. Record the volume.
- You will be given an unknown liquid in a beaker, a triple beam balance, and a graduated cylinder.
- Determine the density of the liquid and identify it using the density table in your book.
- Determine the mass of this quantity of liquid and record it on your data table.
- Repeat this four more times using different volumes of the liquid.
- Determine the mass of the graduated cylinder. Record.

Correct order

1.
2.
3.
4.
5.
6.
7.

responsible for asking the teacher questions that the group cannot answer themselves and for reporting the results of the experiment to the class. The Recorder is responsible for ensuring all members of the group write the correct data gathered during the lab. The Materials Manager is responsible for gathering the materials and for ensuring all members of the group take turns measuring or making observations. By creating a system of interdependence within the lab group, the teacher requires students to think aloud about their ideas regarding the activity. Each student contributes his or her unique perspective and collectively the lab group constructs ideas about the lab experience. Each member of the group is required to complete his or her task for the lab to be accomplished.

Mix up the steps

The teacher takes a cookbook lab and mixes up the steps. An example of a lab addressing the density of an unknown liquid is shown in Figure 1. Before the students can obtain materials, they need to identify the correct order of steps with the help of their lab group. This method requires students to think globally about what they are about to do. They can get a sense of the entire process of the lab by unscrambling steps into their correct order. This method is very popular with teachers who have never experienced an open-ended lab because it makes the students critically think about the process, but does not have the management complications presented in inquiry-based labs.

Give only the procedure

In this method, students are given step-by-step instructions, but the pre-made data table is removed from the lab handout. After reading the procedures and before acquiring materials, students are required to construct a data table for the lab. An example of a lab that requires students to compare speeds of windup toys by measuring distance and time is shown in Figure 2. This method encourages students to get a complete understanding of the process and apply it to organize the anticipated information. The students are required to think about the goals of the lesson and assemble a data table to gather the anticipated information.

Student/teacher round-robin

The teacher initiates the writing of the procedure in this method. The problem to be investigated is introduced and the teacher suggests the first step in the procedure. A student from the class is then asked to suggest the next step. The teacher offers the third step and the process of suggesting steps continues. As an example, students would be asked, "How could you compare the harshness of soaps and detergents?" The teacher would suggest that pH be used as an indication of harshness. A student from the class would give examples of available soaps and detergents to test while the teacher writes this on the board. The teacher would suggest a reasonable amount of samples to test and that 10 mL of each soap and detergent be placed in a 100 mL beaker for testing and writes this step on the board. The teacher would note that exact amounts must be specified in the procedure so that others could duplicate this experiment, and would then elicit the next step from the

FIGURE 2 **The speed of windup toys**

Problem: How do different methods of locomotion of windup toys affect their speed?

1. Choose two windup toys from the bin that have different methods of locomotion. That is, choose one with wheels and one that mimics walking.
2. Make a track for the windup toys using two meter sticks, arranged parallel to each other on the floor.
3. Assign jobs in your group:
   - Starter—wind and start the toy.
   - Timer—give the signal to start and stop.
   - Measurer—measure the distance traveled by the toy
   - Principal Investigator—make sure everyone is on task and the results are reasonable.
4. Wind up the first toy and hold it at the starting point (0 cm on the meter stick).
5. When the Timer says, "Start," release the toy.
6. The Timer should time for 10 seconds and then say, "Stop."
7. The Measurer should mark the exact point the toy was at when the Timer said, "Stop."
8. Repeat the process for a total of five trials per windup toy.
9. Calculate the speed for each trial and the average for the five trials per toy.
10. Compare the speeds for each method of locomotion. Do your results agree with other results found in the class?

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class. A back-and-forth dialogue ensues until all steps are complete. When the students perform the lab and notice deficiencies in the procedure, the teacher would use these teachable moments to emphasize the principles of scientific investigation. This method is effective in drawing out student ideas while simultaneously keeping ideas on-topic due to the embedded teacher direction in the process. Student/teacher round-robin is a good method for a teacher who would like to practice bounded inquiry, a type of inquiry where teachers introduce questioning techniques.

Student/student round-robin

Lab groups are given the problem statement of the lab and are asked to write the procedure for the lab investigation. Given a lab group of four, the first group member writes the first step to the lab, and then the second group member writes the second step to the lab, the third group member writes the third step to the lab, and so on. An example of a lab that addresses the question, "What changes in a pendulum affect the time it takes to swing back and forth?" is given in Figure 3. The lab procedures are written by alternating group members until the procedure is finished. Student/student round-robin gives the students the occasion to generate their own ideas about how the process in science is accomplished. This method also gives students an opportunity to identify different independent variables in an investigation.

Data table only

The procedure is removed from the step-by-step lab and given to the students, leaving only the data table as information. Students tend to understand the data-table-only method well because in standard cookbook labs they often pass over the procedure to first fill in the blanks of the data tables. A lab that compares the density of different sized Snickers bars (the same material) and the density of the same amounts of different types of liquids is given in Figure 4. This method causes students to interpret a graphic organizer (the data table) and think backwards to how data would be obtained.

Concept map

Step-by-step labs are usually easy to convert into concept maps. The linear progression of the process in the lab is represented in a flowchart with pictures, rather than text. An example of a density lab that utilizes different methods of measuring volume is shown in Figure 5. When students interpret

FIGURE 3 **What changes in a pendulum affect the time it takes to swing back and forth?**

Variables to test	How do you *think* the pendulum will be affected?	How are you going to test it?

Choose three variables to test and make data tables in this space.

Conclusion: What is the effect of each variable on the period of the pendulum?

Variable 1:	Variable 2:	Variable 3:

If a pendulum on a clock gains time, what must you do to correctly adjust the pendulum?

the concept map or flowchart, they internalize the process and see the larger intention of the laboratory experience. When students are comfortable with this experience, they can create their own concept maps of laboratory investigations.

Report results in paragraph form for replication

This method simulates the process scientists experience in the course of publishing in a journal and receiving verification from other scientists. The teacher reports the results of the lab in paragraph form and the students are to replicate the lab. This method tends to work best with lab experiences that illuminate properties of materials. An example of a lab showing properties of reflection and transmission of pulses in springs with different spring constants is shown in Figure 6. Students are required to work backwards to produce the problem, procedure, and data table that facilitates their understanding of how scientists think.

Independent variable and dependent variable

Students are given only the independent variable and dependent variable, and are expected to determine the levels of independent variable and the procedure from which to find the relationship between the independent variable and the dependent variable. Students are asked, "How is energy absorbed when matter changes state?" Students are also given the independent variable, time measured in minutes, and the dependent variable, temperature of water measured in degrees Celsius. Students would be required to write out a procedure to test the cause-effect relationship between these two variables. This method resembles the process students go through to complete a science fair project. There are several opportunities to pursue open-ended problems with this method.

Only the first few steps

Students are given only the problem statement and the first few steps of a lab experience and are expected to write the remainder of the procedures and the data table. This method gives students initial direction on the procedures of the lab, but requires students to think through the problem being explored to how the course of action will progress.

Only the problem statement

Students are required to develop a procedure given only the problem statement. Being the least guided of the reforming methods, students are to generate the method to answer a question scientifically. For example, students can be asked, "What is the effect of antifreeze on the boiling point of water?" The teacher can present the given materials, or fulfill student requests for materials. This method is the closest to scientific inquiry and is also called bounded inquiry method.

Teachers who would like to eventually be competent in teaching inquiry learning, but have little background supporting the process, can begin by altering cookbook labs to create a more critical-thinking environment in their class. Once teachers see evidence that the management of

FIGURE 4 **Density comparisons**

Different sizes of the same material

Measurement	Bite-size Snickers	Fun-size Snickers	Full-size Snickers
Mass (g)			
Length (cm)			
Width (cm)			
Height (cm)			
Volume (l × h × w) (cm^3)			
Density (m/v) (g/cm^3)			

How do the densities of the different sizes of Snickers bars compare? Should they be the same? Why or why not?

Same sizes of different materials

Material	Mass of empty graduated cylinder (g)	Mass of graduated cylinder and liquid(g)	Mass of liquid (g)	Volume of liquid (mL)	Density of liquid (g/cm^3)
Fresh water					
Salt water					

open-ended labs is possible, they are more likely to have an inquiry-based sequence of instruction. For teachers unwilling to make the large leap from traditional cookbook labs to inquiry labs, reforming the cookbook labs into activities that require more critical thinking from their students may be the first steps in the right direction.

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FIGURE 5 **Concept map as procedure**

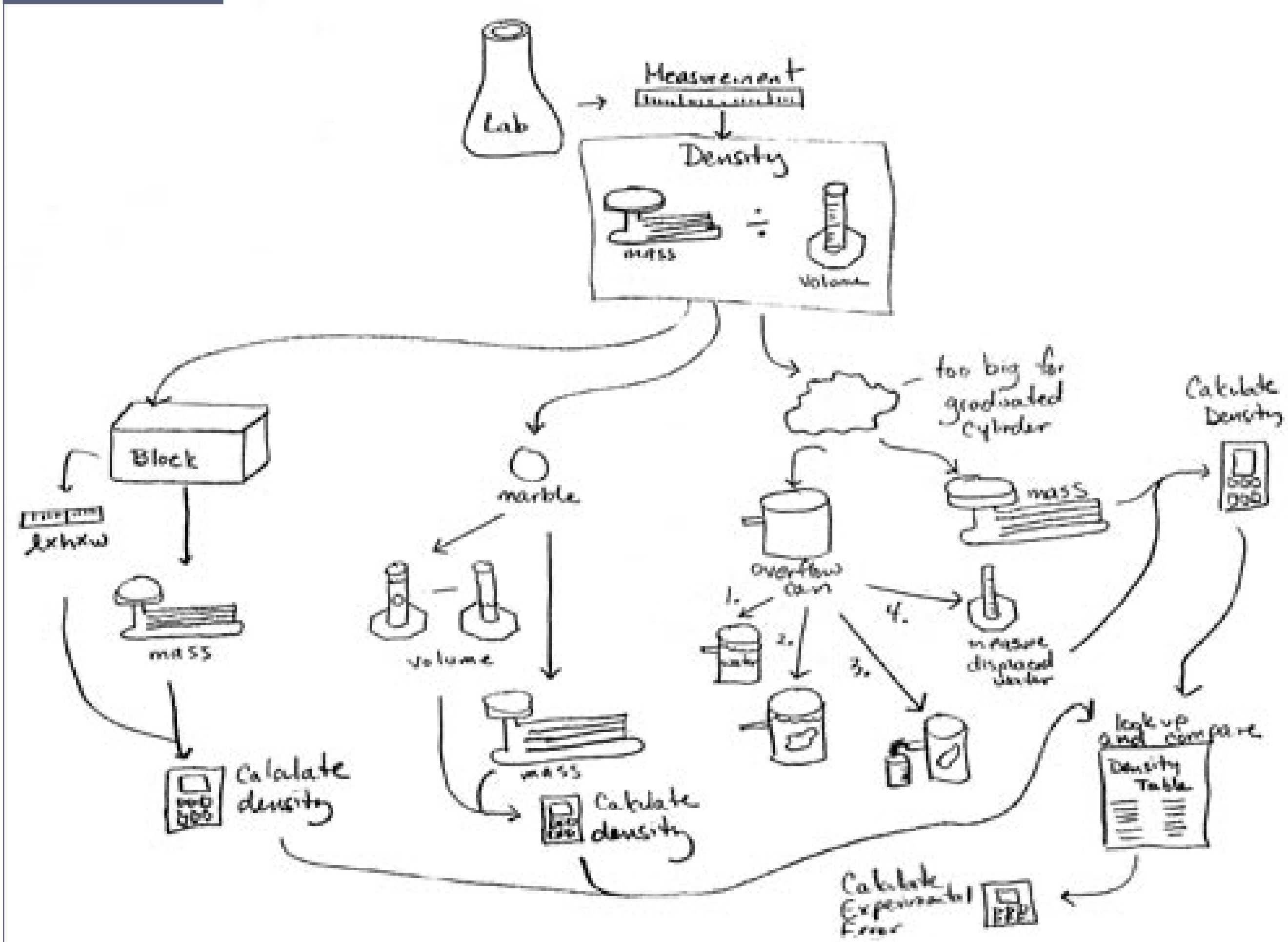

FIGURE 6 **Waves-in-a-coil-spring results**

This experiment included a detailed study of waves. When one small-diameter spring was stretched to a length of 10 m, a single pulse was sent through. The speed was the same going out as it was coming back. The shape of the pulse was the same in each direction.

The shape of different pulses in the same spring was changed. There was no change in the speed of the pulse even though the shape was changed by the experimenter. The size of the pulse was also changed. The speed of the pulse was not affected by this change.

The tension in the spring was tightened. The speed of a single pulse was faster than the speed observed previously. Since the speed changed, the more tense spring would be considered to be a different medium.

Two pulses that were on the “same side” of the spring were sent from each end of the spring and collided in the middle of the spring. Two things happened. They passed through each other and when they met their amplitudes increased. It was as if the amplitudes of the two smaller pulses added to make a large pulse at the exact moment they met. They then passed through each other. Two pulses that were on the “opposite side” of the spring were sent toward each other from either end of the spring. They also passed through each other, except that their amplitudes got smaller as they met. It was as if their amplitudes subtracted when they met.

When two springs of different diameters were attached, a single pulse was sent through them from the smaller diameter spring to the larger diameter spring. When the pulse hit the junction, part of the pulse transmitted through to the next spring and part of the pulse reflected back on the same side that it started. When the pulse was sent from the opposite direction (the larger spring to the smaller spring), part of the pulse transmitted through the junction and part of the pulse reflected back along the larger spring. This reflected pulse was flipped over (inverted).