Rethinking Laboratories

Tools for converting cookbook labs into inquiry

By Mark J. Volkmann and Sandra K. Abell

Although inquiry-based science is the buzz these days, many curriculum materials are still based on traditional approaches that fail to engage students in inquiry. We created an inquiry analysis tool and adaptation principles to help teachers evaluate and adapt laboratory instructional materials to be more inquiry-oriented. Our inquiry ideas are based on the National Research Council's (2000, p. 25) essential features of inquiry, which state students are doing inquiry when they:

- Are engaged with scientifically oriented questions;
- Give priority to evidence;
- Formulate evidence-based explanations;
- Compare and evaluate the merit of explanations; and
- Communicate and justify explanations.

Classroom teachers support inquiry when they raise productive questions that provide opportunities for students to define variables and develop procedures, challenge students to look for patterns in data, guide students as they develop evidence-based explanations, and create situations where students communicate and justify explanations on the merit of the evidence (Elstgeest 2001).

Where to begin?

The two-stage inquiry analysis and adaptation process allows teachers to evaluate laboratory instructional materials and revise them to incorporate more inquiry. Starting with the inquiry analysis tool (Figure 1), teachers use a set of questions to help decide how much the instructional materials reflect an inquiry orientation. Next, using the adaptation principles (Figure 2, p. 40), teachers revise a lab to incorporate the essential features of inquiry.

To demonstrate how these tools work, a typical cookbook laboratory, the "rusty nail lab," is examined. Using the inquiry analysis tool, the aspects of the lab that do and do not support inquiry are identified. Next, the lab is transformed using the adaptation principles to reflect an inquiry approach to science instruction.

A cookbook example

The rusty nail lab is a traditional cookbook lab organized around five familiar steps: purpose, procedure, data, analysis, and conclusion. The purpose step includes the objective of the activity—to demonstrate ways to prevent a nail from rusting—and an explanation of the underlying principles of rusting. Rusting is due to the oxidation of iron, which occurs when iron comes in contact with air (oxygen), water, and an electrolyte. The procedure describes the recipelike steps students follow in order to verify this explanation and includes a data table for recording observations. Suggested strategies for teachers to prepare students

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for the lab include a lecture on rusting, assigned readings of the lab's explanation of rusting, assigned writing of the procedural steps, or copies of the data table.

During the lesson, each lab group follows the recipe by preparing four nails for observation: one dipped in oil; one half-coated with paint; one half-submerged in salt water; and a control left untouched by oil, paint, or salt water. On subsequent days, students observe the nails and record changes in the prescribed characteristics of shininess, texture, color, and extent of rust. On the last day of observation, students analyze the results. Answering prescribed lab questions, students identify which nails rusted and which did not, select the conditions that prevented the nails from rusting, and list the conditions necessary for nails to rust. Students describe which preventative measure worked the best and give a definition of rusting and rust (most likely by repeating the background information provided in the lab). The teacher summarizes the results and assesses student understanding by grading their responses to the analysis and conclusion questions.

Applying the inquiry analysis tool

We analyzed the rusty nail lab in a systematic way by asking the questions found in our inquiry analysis tool (Figure 1). What we discovered is not at all surprising—the cookbook style of the lab does not represent the essential features of inquiry.

1. *Are learners engaged with scientifically oriented questions?*
   No. Neither the teacher's explanation preceding the lab, nor the purpose statement, includes questions. No effort is made to involve students in generating questions or connecting the concept of rusting to their lives.
2. *Did learners give priority to evidence?*
   No. The lab does provide opportunities for students to use their senses to collect data and make judgments about shininess, texture, and degree of rusting. However, learners do not decide what data to collect. Instead, the book provides an explanation for learners to verify as they follow recipelike directions.
3. *Did learners formulate evidence-based explanations?*
   No. Students had no opportunity to provide preliminary explanations. Their analysis consisted of matching observations to the explanation provided. This matching game has little in common

FIGURE 1

Inquiry analysis tool.

Does the material...	YES	NO
1. Engage learners in scientifically oriented questions?		
◆ Do questions guide labs?		
◆ Do students generate, refine, and focus questions for investigation?		
◆ Are questions relevant to students?		
2. Ask learners to give priority to evidence?		
◆ Do students use their senses and instruments to collect evidence?		
◆ Are recipelike procedures presented as the only way to address the objective?		
◆ Do students have opportunities to decide what data to collect or how to collect it?		
3. Encourage learners to formulate explanations from evidence?		
◆ Are students encouraged to provide preliminary explanations?		
◆ Do students generate explanations from evidence?		
◆ Are students asked to explain their reasoning?		
4. Compel learners to evaluate their explanations in light of alternative explanations?		
◆ Do students compare explanations based on how well they account for the evidence?		
◆ Are students asked to revise their explanations in light of evidence?		
5. Expect learners to communicate and justify their proposed explanations?		
◆ Do students have opportunities to discuss their ideas in small groups?		
◆ Do students have opportunities to present their ideas through writing, drawing, or thinking?		
◆ Do students have opportunities to present their ideas to other audiences?		

with learners explaining their reasoning or demonstrating their understanding.

4. *Did learners compare and evaluate the merit of their explanations?*
   No. The students had no opportunity to evaluate their thinking or change their ideas in light of the evidence.
5. *Did learners communicate and justify explanations?*
   No. Students had no opportunity to discuss their ideas in small groups or to justify their ideas either through writing or speaking.

The inquiry analysis tool pinpoints features to change. The rusty nail lab qualifies as "cookbook" because students are given an explanation of rusting (the cake) and a set of instructions (the recipe) and are expected to bake a cake just like the teacher's. There is a reasonable alternative.

Transforming the recipe

The adaptation principles (Figure 2) aim to involve students in scientific inquiry by finding ways to engage students with meaningful questions, evidence, and explanations. We used the adaptation principles to transform the rusty nail lab into an inquiry-based experience for students and used the principles in a course for future secondary science teachers.

The new inquiry-based lab began by engaging students with a challenge. The teacher gave students shiny steel nails and asked, "Where can you put the nail to make it rust?" Students took their nails home to study. Two weeks later, students brought their nails to class and created posters in response to the following questions: "Where did you put your nail? Why did you put it there? Why did you think that would make the nail rust? What do you think rust is?" (Driver et al. 1994). Using their completed poster, students interacted with each other. This assessment of students' prior knowledge about rusting communicated that students were confused about what combination of variables were responsible.

During a discussion led by the teacher, students suggested that water, air, salt, and acid led to the formation of rust. Students were asked, "Is a single variable responsible for rusting, or is some combination of variables responsible?" This question challenged students to design a procedure to investigate the effect of changing one or more variables at a time. A simple planning guide for creating investigations helped students focus attention on controlling variables by asking, "What variable(s) are you testing? What will you change? What will you keep the same? What will you observe? What will the results mean?" (Harlen 2001). Students wrote procedures, designed data charts, gathered materials, and began their investigations.

One group investigated the question "Does salt water cause rusting?" The group submerged a shiny nail in a flask containing 0.1 M sodium chloride (NaCl). As the students designed their procedure, the teacher probed them to check if they were conducting a fair test. When the teacher reminded the group that water also contains dissolved air, the group decided to heat the solution to boiling to remove the unwanted air, thus removing a possible confounding variable. Other questions included, "Does dry salt cause rusting? Does damp salt water cause rusting? Does acid cause rusting?" Each group designed a procedure specific to their question.

Over the course of the next five days, students recorded their observations and discussed emerging patterns. On the last day of observation, the class discussed which variables were responsible for rusting. The teacher listed the variables under investigation and asked students for explanations based on the evidence they had collected. For example, the saltwater group observed no red rust on the nail. The class concluded that salt water alone could not produce rust. Other groups turned up

FIGURE 2

Adaptation principles.

Questions:

1. Change the purpose statement of the activity into a question.
2. Involve students in activities where they generate questions to investigate.
3. Make the question relevant to the students.

Evidence:

4. Throw away the recipe (or parts of it) and give students, groups, or the class opportunities to define variables, develop procedures, set up data tables, and make predictions.

Explanation:

5. Move the teacher's explanations and textbook reading from before the lab to after the lab.
6. Expect students to develop evidence-based explanations as a central step in all lab work.
7. Provide students with opportunities to work and talk together.
8. Engage students in the analysis of data by looking for patterns, using evidence and logic to support explanations, and honing their skills at constructing evidence-based explanations.

Communication:

9. Provide opportunities to present explanations to other audiences through discussion, writing, and drawing.
10. Ask students to evaluate the logic of their explanations in terms of evidence.

similar results and made conclusions related to their variables. However, the group that investigated damp salt water did notice red rust on their nail.

As a culminating activity, each lab group presented a research claim to the class. The claim consisted of their question, their observations, and an evidence-based explanation that identified the variables responsible for rusting. This assessment activity afforded information about each groups' developing understanding of the variables affecting rusting. When all groups had completed their claims, the teacher summarized the findings by providing a scientific explanation of rusting: Rust results from the combination of iron, oxygen, and water in the presence of an electrolyte to produce iron oxide (Fe_2O_3). This is an oxidation-reduction reaction where the iron loses electrons (oxidation) and oxygen gains electrons (reduction). The role of the electrolyte is to complete the circuit in the transfer of electrons.

According to Driver et al. (1994), students are more likely to expand, integrate, and change their thinking if their ideas are challenged by a new problem. As an assessment activity, the teacher challenged students to use their new ideas to explain in writing how and why paint and oil can protect iron from rusting, an idea provided by the original rusty nail lab. Responses from this challenge served as a summative assessment for how well students understood the variables responsible for rusting.

From cookbook to inquiry

The adaptation principles (Figure 2) are 10 possible actions teachers can use to address the lack of inquiry associated with any lab activity. These actions help students engage with scientifically oriented questions, focus attention on evidence, construct explanations from evidence, and justify and communicate explanations. The number of principles chosen is dependent on what is learned from the inquiry analysis tool and whether the inquiry is partial or full (Martin-Hansen 2002).

The first action was to change the purpose of the lab to a question (Figure 2, Principle 1), challenging students to solve the problem of where to put the nail to make it rust. This placed the activity outside the classroom and into the students' world. Rather than starting with the potentially alienating "why" question, students explored the phenomenon of rusting. As students observed a nail over a two-week period, they formed an interest in how it changed. As students created posters, they focused on the evidence they had collected. Discussing the variables that affect rusting provided an opportunity to generate new questions for investigation (Figure 2, Principle 2). Giving students responsibility for science activities helped them feel ownership, supported their curiosity, and made the activity relevant to their lives (Figure 2, Principle 3).

To help learners give priority to evidence, the recipe was discarded and opportunities to define variables, develop procedures, and set up data tables were provided (Figure 2, Principle 4). In the transformed rusty nail lab, students had opportunities to decide what data to collect and how to collect it. Observing and recording changes during the investigation provided opportunities for students to use their senses to focus attention on patterns in the data. By planning how to investigate a combination of variables that influenced rusting, students gained experience designing procedures and controlling variables. In addition, this activity provided opportunities for students to be creative, make decisions, and exercise curiosity.

Moving the teacher's explanation from the beginning to the end of the lab allowed room for the students to construct preliminary explanations about rusting (Figure 2, Principle 5). Postponing the teacher's explanations shifted the responsibility of explaining to students (Figure 2, Principle 6). The new lab engaged students in group work (Figure 2, Principle 7). Students were asked to explain patterns in the data and use evidence and logic to support their explanations (Figure 2, Principle 8). By placing students in situations where they communicated their explanations to others and shared their evidence-based claims (Figure 2, Principle 9), they were compelled to evaluate the adequacy and logic of their explanations and to revise explanations in light of evidence (Figure 2, Principle 10). Finally, challenging students to solve a new problem using their explanation promoted thinking and deepened understanding.

We have shared these tools with many high school science teachers, who have found them easy to use, consistent with state and national standards, and instrumental in transforming their laboratory instruction. ■

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