Modifying Cookbook Labs to Mentally Engage Students

by Robert L. Clark, Michael P. Clough, and Craig A. Berg (2000)
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Introduction

Developing deep, robust, and long-term understanding of science concepts is but one aim of the *National Science Education Standards (NSES)*. The desired state also includes an understanding of the nature of science and the attributes and skills that make for effective science inquiry (NRC, 1996). The task is daunting and reaching the desired state will not occur without rethinking the role of laboratory activities and teacher behaviors. Unfortunately, pre-fabricated inquiry activities rarely meet the unique circumstances that exist in our diverse schools. Yet science teachers are far too busy to invent every lesson from scratch so these experiences are more consistent with the desired state set forth in the *NSES* and NSTA's *Pathways to the Science Standards* (Texley and Wild, 1996).

In rethinking laboratory activities, too often a false dichotomy is presented to teachers that students must either passively follow a cookbook laboratory procedure or, at the other extreme, investigate a question of their own choosing. These extremes miss the large and fertile middle ground that is typically more pedagogically sound than either end of the continuum (Lazarowitz and Tamir, 1994). Effective science teachers creatively modify activities to make explicit students' relevant prior knowledge, engender active mental struggling with that prior knowledge and new experiences, and encourage metacognition (Hand and Keys, 1999). Such modifications, however, make the teacher's role in student learning far more critical. Much has been written regarding the unnatural nature of scientific thinking (Cromer, 1993; Toulmin, 1972; Wolpert, 1992) and its implications for science education (Clough, 2000; Matthews, 1994; Shamos, 1995). Without-well reasoned teacher intervention in both the designed lab structure

and its implementation, students will rarely create meaning similar to that of the scientific community.

What follows is an example of an extended laboratory activity that was modified from a common cookbook approach for determining the mass percent of water in a crystal. This modified approach significantly enhances students' understanding of matter, its properties, the nature of science, and inquiry. All this is accomplished using only an inexpensive chemical ($CuSO_4 \cong 5H_2O$), heat source, test tube, test tube holder, ring stand and balance. What makes this activity an effective learning experience is the role of the student and teacher in investigating the phenomenon.

Introducing the Lab

The activity begins by first having students describe the observable physical properties of copper (II) sulfate pentahydrate. The compound appears as a blue crystal and, when given more time, students observe more closely its texture, odor, state, and crystalline shapes. Positive non-verbal behaviors, wait-time, and accepting students' responses are important for acquiring this and any other information. Once their observations are exhausted, the name of the substance is provided and students determine its formula unit—sometimes by looking at the bottle label and sometimes by using rules of nomenclature based on the formula name. Students are genuinely perplexed and skeptical when they hear that this substance has water molecules positioned nearby as it has no outward signs of being wet. This issue raises significant interest regarding several questions, including the nature of hydrates and how the amount of water molecules in a formula unit is determined.

Encouraging Student Thinking and Conceptual Understanding

"Water?" the teacher skeptically asks. "What evidence of water appears in this container?" None can be found, but student engagement is sustained by asking, "What substances from your everyday experience appear dry, but actually contain water?" Such questioning, in tandem with appropriate wait-time and positive non-verbal behaviors, encourages students to offer examples familiar to them that exhibit this same quality such as modeling clay and gelatin. When pursued, their evidence for these claims include that their exemplars "dry out" when left in the open air. This sets students up for the possibility that this hydrate not only may contain water, but also a procedure they might use to drive off the water. Once students come to this vital insight, they are asked how they might drive off the water. Some students suggest letting it stand out in the open air and, if time permits, that approach can be tried. Before beginning that inquiry, students are asked how the driving off of water might be accelerated. With little difficulty students suggest heating it. This raises another series of questions regarding how the percent mass of water driven off might be determined. To ensure that students are mentally engaged in the process, they are asked to think about how percentages are calculated to determine their grades or other familiar everyday examples. The following calculation emerges through a negotiation with the students:

$$Mass\,\%\,of\ water = \frac{mass\ of\ water\ driven\ off}{initial\ mass\ of\ hydrate} \times 100\%$$

At this point students have a general strategy for driving off the water, and a formula for calculating the mass-percent of water in a hydrate, but they now are required to work in groups of two in composing a more detailed procedure that includes what equipment they will need. Students share ideas as they work, and while procedures may differ somewhat from group to group, if safe they are accepted. When a procedure is rejected for safety reasons, students are told the concern and that they must find another way of accomplishing that particular task. The

students need to produce a complete experimental design which includes a clear description of each step in their procedure, needed equipment and pictures showing how the equipment will be used. Typically, by the end of a 50 minute class, students are ready to begin their work the following day.

While students are setting up their equipment, the teacher moves around observing, listening, and asking questions concerning individual methods and reasoning. In a lab setting, students reveal their conceptions and beliefs by what they do and say. During this time students talk specifically about the science involved and provide perceptive teachers with insights into their thinking. Often what students do does not reflect what they say and may expose weaknesses or conflicts in their current conceptual frameworks. With well phrased teacher questions, students see discrepancies in their thinking, and consider alternatives without being told exactly what to do. With the exception of unsafe practices, teachers must avoid judging students' ideas, and instead pose questions that mentally engage students in the content and process under scrutiny. To do otherwise teaches students they are not accountable for their thinking or actions as the teacher will simply correct unfruitful decisions.

At times, students simply ask whether they are right and these requests for teacher authority can be circumvented by asking questions like "How will that step provide the information you want?" or "What difficulties do you expect with the procedure you have developed?" These provide a window into students' thinking that can be used by teachers to structure further questions. This approach demands student mental engagement and usually moves them back on track to testing their ideas rather than yours. Conversely, teachers who judge ideas sacrifice students' thinking, creativity and accountability. Students must be encouraged to confront their currently held ideas (NRC, 1996; Osborne and Freyberg, 1985;

Posner *etal.*, 1982; Saunders, 1992).

After students have collected their data and completed their calculations, results are shared on the board. Brace yourselves, because the reported percent water values may range between 2 - 70 %, but the experience initiates a fitting and essential moment for students to engage in evaluating the results of scientific investigations, data, and theoretical models (NRC, 1996). And having first experienced the activity, students can now better deal with the abstractions and ideas necessary to explain their results (Colburn and Clough, 1997). Their conceptions are again revealed during a discussion that highlights areas of concern.

One concern that arises is that groups with larger percentages of water are said to have started with more copper (II) sulfate pentahydrate. Of course, this should make no difference and effective questioning, providing different scenarios, and having students calculate the percent mass of water for each scenario convinces most students that the starting amount should have no bearing when considering percent water. The discussion then moves to other potential problems including, but not limited to, errors in massing, calculation errors, and how one ensures that a hydrate has been completely dried. For instance, students often flip-flop the mass values in the percent-mass equation which accounts for the values clustering around 64%. To force students to generate an explanation of this odd data, teachers might ask, "In what way do these results compare to those clustered around 36%?" Student responses can be followed with, "How might we then explain the existence of these results?"

How to ensure that the hydrate has been completely dried requires a conceptual insight that students find very difficult. Students often question how much heat is necessary to drive off all the water. Here the teacher should direct students back to the observations students made during the heating of the hydrate. They are in agreement that, upon initial heating, condensation

appeared at the opening of the test tube. Some students claim that with prolonged heating the substance began to change color, but this still does not answer the question regarding how to determine when a hydrate has been sufficiently dried. Here again the teacher's role is critical! A straightforward but essential question is, "What happens to the mass of the remaining substance as water is being driven off?" Students know that the mass of the remaining substance is less which then sets them up for the following question, "After you have driven off all the water, what will continued heating do to the mass?" Students are quick to piece together that once all the water has been driven off, the mass of the remaining compound will cease to decline with further heating. Another approach that students often suggest is observing for cessation of condensation at the top of the test tube and then heating a few more minutes to ensure the hydrate is sufficiently dried. While this is not quantitatively precise, it does make clear to students that more than one way exists to solve their concern.

Students enthusiastically enter the lab a second time with a significantly more robust understanding of hydrates and how to go about determining the mass-percent of water in copper (II) sulfate pentahydrate. After emerging from the lab and sharing their data the second time, students are more confident that they have a reproducible value for the mass percent of water. Most numbers shared are clustered in a small range around 36 % and students' enthusiasm and confidence grows with each addition placed on the board. Their overt response reveals acceptance or skepticism of new data. In some instances, a few exceptions exist around 64 %, but because of the prior discussion, *students* are quick to suggest and check whether these are simply calculation errors.

To complete the lab, students are asked to apply the Law of Conservation of Mass to explain a relative decrease in the mass of the system. Through measuring a decrease in mass of

the remaining solid, but seeing the water vapor condense at the top of the test tube, students have evidence that mass does not disappear but, in this case, merely changes state and enters a larger system. This, of course, could lead to another interesting investigation to determine whether students can empirically account for the decrease in mass of the hydrate. This effort is worthwhile as much evidence exists that while students will accurately verbalize the conservation of mass law, they hold many misconceptions regarding the mass of substances in different phases (Stavy, 1990).

Teachers are the Key!

Despite the pervasive and critical role of curricula, the evidence is clear and overwhelming that teachers are the most influential factor in educational change (Berliner, 1989; Fullan, 1991; Langer and Applebee, 1987; Penick, Yager, and Bonnstetter, 1986; Shymansky and Penick, 1981). Effective teaching is a highly interactive activity and curriculum alone will not create this atmosphere. Teachers translate curricula through their decisions regarding the depth and breadth of content to teach, how meaning will be conveyed, and why learning is important. However, teachers need not create a new curriculum from scratch or change everything they do (Colburn and Clough, 1997). Modifying the structure of pre-existing cookbook labs, asking effective questions such as those suggested here, incorporating appropriate wait-time, acknowledging and playing off student ideas, and exhibiting positive non-verbals are all key for creating the mentally engaging and productive environment set forth in the *National Science Education Standards* and *Pathways to the National Science Education Standards*.

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