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Investigating Solutions through Inquiry

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ABSTRACT: In this article we discuss how many activities have valuable ideas, but important modifications must be made to make the activity more effective and mentally engaging. This article discusses the modification of a "cookbook" solubility lab into an inquiry activity, which increases student decisions and the promotion of higher-order thinking skills. We also address the critical role of the teacher in making the lesson effective. *This article promotes National Science Education Standards A, B and G and Iowa Teaching Standards 2, 3, 4, and 6.*

Science activities and demonstrations are not difficult to find. Implementing such activities in a manner that promotes deep mental engagement of students is difficult. Many people think that using an activity along with a science concept is effective purely because it is fun for students or because it is "hands-on". Yet, many "hands-on" activities are not "minds-on." They do not require students to actively think about what they are doing, often resulting in student products that all look the same (Alesandrini & Larson, 2002). Instead, many "hands-on" activities have students mindlessly follow preset procedures. Little, if any, understanding or thinking is required. Hands-on activities can be useful if the teacher is able to help the students make connections from the activity to the targeted science content. Encouraging active mental engagement is perhaps one of the biggest difficulties of teaching, but is essential if deep learning is to be promoted.

Activities that are more traditional or "cookbook" can become excellent resources if the teacher knows how to modify the activity or experience so that students are more meaningfully engaged. We have found several such activities that, with some tweaking , develop into an activity that challenges students to well beyond rote memorization and following linear instructions. This article describes an activity that we have modified from a "cookbook" activity into one that places greater expectations on our students.

Our Decision to Modify

The original activity made many decisions for students – encouraging little mental effort. Students were provided with all the equipment necessary for the activity, a step-by-step procedure, a pre-organized data table, and even an analysis section that explained exactly how to manipulate the data. Students would be able to complete the activity with little or no thinking. The activity also required little or no actions of the teacher beyond handing out materials and supervising lab safety. We know that if students are to gain the most from any activity, it requires the teacher to carefully monitor, assess, and guide student thinking by posing carefully crafted questions which help students make connections to the desired learning outcomes.

Students' Background Knowledge

Whether they realize it or not, students have had many experiences with solutions in the past. Perhaps it was the time he or she added a packet of Kool-Aid mix into water, or even the simple combining of salt and water. Yet, these are valuable experiences all the same. It is important for the teacher to find out students' prior experiences with solutions, which can be accomplished through question such as,

- "What are some examples of water mixtures you have seen before?" or
- "What happens when you add salt to water?"

Connecting the target science content with student prior experiences can help the teacher find out what students are thinking and what they believe happens when solutes dissolve.

Even though students have had their own experiences with solutions, they likely have never considered the processes at work. We use a simple demonstration of adding salt to water to encourage students to visualize what happens during dissolving. We ask leading questions to help students make more detailed observations such as:

- "What happens as you continue to add more salt?"
- "What settles at the bottom?"
- "What effect does stirring have on the solution?"
- "What happens when you stop stirring?"
- "What do you think might happen if you were to heat it?"
- "What factors might affect the amount of salt that can be dissolved in water?"
- "How could you test the effects of different factors?"

When students discuss these questions they may suggest ideas that are in conflict with accepted scientific explanations. For example, a student may suggest that when salt is added to water it "disappears".

While it is understandable and well-intended to want to correct a student's wrong notion, it is more effective to respond with questions that encourage the student to consider why his or her idea is problematic. While a student will likely accept a teacher's correction to their misconception, it rarely leads to true conceptual change (Appleton, 1993). Examples of questions to use to help a student address their misconception include:

- "What do you mean by the term 'disappear'?"
- "What could you do with the container of water to demonstrate that the salt doesn't simply "disappear?" or more directly,
- "What would you observe in the container if you were to evaporate all the water?"

To put the question into action you could ask students what would happen to a small puddle of salt water if it was left out overnight. If students are unsure, this experiment is easily carried out for the next class period.

Setting Up the Experiment

After students have had a chance to more carefully observe dissolving, we ask students,

- "How could you determine the effect that temperature has on the amount of salt that will dissolve?"

We have students discuss in pairs to begin developing an approach to answer the question. As students begin their discussion, we walk around the room to listen and pose questions to help guide students' thinking. Questions that we commonly pose include,

- "How can you be sure you dissolved the maximum amount of salt?", or
- "How will you determine how much salt did not dissolve?"

Students will soon feel ready to begin testing. Some groups may propose testing a small number of temperatures, while others may suggestion testing a large number of temperatures. Be aware that having students do a large number of temperatures can take a lot of time, so decide beforehand how much time to devote to this testing. Discuss with the class how they can minimize the number of tests needed while still achieving the desired results. Use questions to guide the class toward seeing that different groups could test different salts (KCl, KNO_3, and $NaCl$) or that using ten different temperatures may be excessive when only 5-6 are needed to observe the same trends. We typically ask students,

- "How might we work as a class to more quickly collect our data?", or
- "What is the benefit of testing a large number of temperatures?
- What is the benefit of testing fewer temperatures?"

Students may also have some trouble deciding which temperatures, what volume of water, or what amount of salt to use. These issues can be addressed through questions such as:

- "How much water will you use? Why?"
- "How much salt will you try? Why?"
- "How can we use what we know about liquid water and temperature to inform our tests?"
- "How could we get a rough idea of the maximum amount of salt possible to dissolve?"

While groups conduct testing, if you observe multiple groups having troubles with their procedure or conceiving how to conduct a test, take time to bring the class back together to discuss how they can overcome these problems. Whole class discussions have many benefits: they give students who have found a solution to a problem the opportunity to help others, they foster collaboration, and they give students ownership instead of relying on the teacher to provide solutions.

When all students have developed their procedures, be sure to check them over and address any safety concerns. We had the students turn in their procedures so we could look over them prior to the next day's class. Additionally, we have the students discuss their procedures as a class to see if they wish to all work with one procedure, or to go with various procedures. This discussion also gives students the opportunity to discuss the merits of different procedures, and to provide their rationale. This is also an opportunity to reiterate the purpose of this testing, including what data the students plan to collect and how they plan to record their data.

We find that most students propose adding one gram of salt at a time to a specific temperature of water. The solution is stirred until all the salt in the mixture dissolves. This process is repeated until some salt remains undissolved. Depending on the level of the students, this procedure might be fine. Yet, for more advanced students we might ask,

- "Imagine you have added your tenth gram of salt, and only some of it dissolved. How will you know how much of the tenth gram did dissolve?"

To address this question many students will suggest adding an excess amount of salt to a specific temperature of water and stirring for a certain amount of time, then filtering out the salt that did not dissolve and subtracting the excess mass from the original mass. We push the students concerning this procedure by asking,

- "How will you be sure that the mass of the excess salt is accurate?" and
- "Why will water be a problem in this procedure?"

For the most advanced students we ask,

- "Imagine you have salt that has not dissolved in a solution that is at room temperature. You then heat the container and observe the excess salt is now dissolved. What do you think will happen as the hot mixture cools?"

This discussion encourages students to reconsider how they investigate the effects of temperature on the amount of salt that will dissolve. Students usually realize that changing the temperature is not necessary, they can instead adjust the amount of salt added.

Students come into the classroom with a wide variety of prior knowledge and experiences. Within the class, each student's ability to handle increasingly complex cognitive tasks will fall along a wide continuum. This series of discussions can be modified to the needs of your students, but in all cases they provide students with the concrete experiences that we will draw upon during future discussions.

We note here that our goal is not simply for students to be able to construct a perfect solubility curve. Well beyond this one goal, we want students to gain valuable inquiry skills, critically think about the dissolving process, and more accurately understand how scientists actually work.

Into the Lab

After discussing the procedures and checking the students' procedures for safety concerns, the students begin their investigations. During testing we walk around to observe and ask questions about what students are doing and any problems they may have come across. To push student thinking we ask,

- "How will you be sure that your final results don't include any undissolved salt?" or
- "How will you know when the salt is finished dissolving?"

When the students have finished their investigations, we bring the class back together to discuss their results. While discussing, we continue questioning students to help them think through what was going on throughout their testing.

- "What affects did temperature have on the amount of salt dissolved?"
- "What similarities or differences do you note among the different investigations?"
- "Why do you think temperature affected the amount of salt that dissolved?"
- "How could you present your results so that someone who didn't do this experiment would understand your results?"

To assess student understanding of their investigations and inquiry skills, we have the students write a report of their procedure, results, calculations, and analysis of what they observed and why they made the decisions they did.

Linking to Content

We avoid using the term "solubility" with students until after they have come to understand the dissolving process by way of the lab experiments. Only after we are confident that conceptual understanding occurs do we introduce new vocabulary. We proceed with:

- "What happened as you continued to add more and more salt?"
- "How did you know that the maximum amount of salt had dissolved?"
- "What happened when you changed the temperature?"
- "Why do you think the salt stopped dissolving at a certain point?"

The students will have observed that salt eventually will no longer dissolve, and that as temperature increases the amount of salt that dissolves also increase. These ideas can now be linked to "solubility" since the concept can be connected to a concrete experience. At this time we also introduce the standard units of solubility and have students begin to convert their own data from the experiment into standard units.

Addressing the Nature of Science

Throughout the school year we look for opportunities to incorporate discussions about the nature of science. Lessons regarding the concept of solubility provide such opportunities. We ask questions like those listed below to generate discussion about the nature of science. We include some of these discussions during students' investigations, and others after the investigations are through.

- "How does your investigation compare to what scientists do when they are trying to solve a problem?"
- "Why might scientists have common units for solubility?"
- "What is the value of discussing our results? How is this like what scientists do?"
- "Many of you had different procedures to investigate the same question. What might this indicate about the existence of one "scientific method"?"
- "Most of you worked with other classmates, discussing ideas, and asking questions. How does this demonstrate that scientists do not just work alone in a lab?"

Irregardless of when the teacher discusses the nature of science, explicitly addressing the nature of science is necessary if students are to gain valuable insight on how science really works (Abd-El-Khalick & Lederman, 2000; Clough & Olson, 2004; McComas, 2004).

The Teacher's Role in the Science Classroom

The teacher needs to be aware of what students are thinking. This is accomplished by continually asking questions that encourage students to express their ideas. Yet, questions are not enough. Teachers must use wait-time after a question is asked so that students have time to develop their ideas. Provide wait-time after a student responds so that other students are given the opportunity to think about what was said and respond with their own ideas. Student ideas can also be used to guide the discussion and lead to a deeper understanding of the content. Using student ideas in discussions shows that the teacher values the students' thinking and encourages further student responses. The use of positive non-verbal behaviors (facial expression, hand motions, etc.) show anticipation of student ideas, and show students their ideas are valued and wanted.

Conclusion

The original activity demanded little from students. Our effort to modify the activity involved shifting the responsibility, decision-making, and ultimately the cognitive demand from the lab directions to students. We accomplished this through carefully crafted questions which uncovered students' prior knowledge, promoted discussion and collaboration, and demanded deeper levels of critical thinking. Our students come away from this activity with a much greater understanding of the concept of solubility. They also gain confidence in their ability to design their own experiments, organize their data, and interpret their results. We find the work we put into modifying traditional lab activities to be intellectually stimulating, and well worth the effort as we observe the difference it makes for students.

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