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Circuits without Wires?: Helping Students Understand the Power of Ions

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CIRCUITS

WITHOUT WIRES?

Helping Students Understand the Power of Ions

by **Elizabeth Potter and Caroline M. Kelly**

ABSTRACT: The activity described here provides an inquiry experience using familiar materials to promote student exploration and understanding of ions and ionic compounds. Familiar materials throughout the laboratory help students relate science to the real world and students are able to use their understanding of those materials. This activity uses an inquiry approach that requires students to make more decisions about their experiment, but does not expect students to discover scientific ideas. This article identifies many ways that the nature of science should be incorporated into the learning experience so that students improve their understanding of what science is and how it is done. *This article promotes National Science Education Content Standards A, B, and G, and Iowa Teaching Standards 1, 2, 3, and 4.*

Introduction

In teaching chemistry, many opportunities exist to provide students engaging and exciting laboratory experiences. When these experiences are properly structured and implemented, they provide students hands-on and minds-on experiences that set a firm foundation for understanding complex concepts. Unfortunately, too often students simply follow step-by-step procedures (hands-on) that do not encourage them to think about what they are doing (minds-off). Moreover, many science activities introduce complex equipment too soon and this may hinder students' understanding of desired concepts (Olson & Clough 2001). This can result because the novelty of the equipment draws students' attention away from the conceptual nature of the laboratory activity, or the equipment may wrongly be conflated with the concepts being addressed. Lunetta *et al.* (2007) provide an example where a very bright honors physics student, after having used a bulb holder in a batteries and bulbs activity, thought the bulb holder was an essential part of the electric circuit.

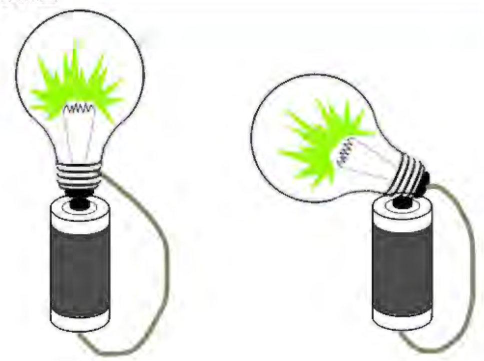
effective laboratory experiences require attention to several important teacher decisions such as developmental appropriateness of the content, selection of appropriate materials that will promote desired conceptual understanding, and the teacher's role in interacting with students to help them make desired links. Deep and meaningful learning takes time, and teachers must be careful not to rush through activities while students are wrestling with the concept at hand. When teachers rush ahead, students are forced to consider new concepts onto an already shaky foundation. To stay up, they are forced to accept at best a superficial understanding of the content, or memorize as much as they can without understanding.

By keeping in mind how students learn, the nature of science, and the goals that we have for students, learning experiences may be better structured and carried out so that students will develop a deep understanding of the content being taught. In teaching about ions and ionic compounds, a common laboratory experience or demonstration has students complete a previously broken circuit by placing wires in various solutions. The intent is to illustrate that an ionic solution will complete the circuit as evidenced by the light bulb glowing. The following article will look at how to address students' understanding of the materials being used, as well as how to make this experience more mentally engaging.

Into the Lab

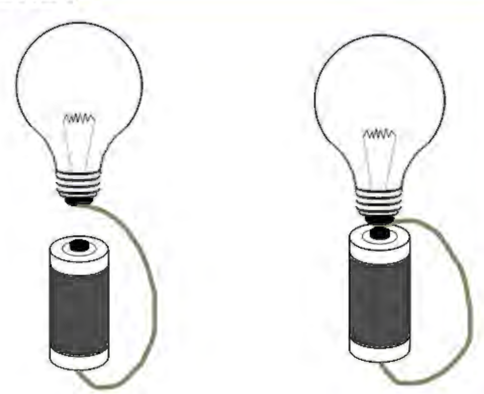
In the first portion of the activity, students are given a battery, a wire, and a light bulb. They are then asked to complete a circuit. Some students will have a strong understanding of the principles necessary to illuminate the bulb and will complete the task quickly (Figure 1); other students won't (Figure 2). While this lab is not about batteries and bulbs, students need to truly understand how a circuit works to follow the logic of the ions activity and make the desired conceptual link. Without this prior knowledge, the equipment used to illustrate that ionic solutions will complete a circuit becomes a black box that prevents students from developing the desired conceptual understanding.

FIGURE 1



Common wiring arrangements by students that DO cause the bulb to illuminate.

FIGURE 2



Common wiring arrangements by students that DO NOT cause the bulb to illuminate.

The time and effort devoted to helping students understand circuits, and drawing students' attention to the idea that moving electrons are what cause the light bulb to illuminate are crucial. Without this knowledge, students will not understand the secondary part of the lab and why wires connected to a battery and light bulb are being placed in beakers of solutions. Students who don't understand electrical circuits and the explanation for electrical current will either be mystified by the new experience, or interpret it wrongly based on their prior misconceptions. Because this portion of the lab is an important set-up to the rest of the experience, appropriate time must be devoted to it.

After their initial experiences attempting to light a bulb with one wire and a battery, students should share their successful and unsuccessful configurations with the class. The teacher might ask, "What are common features of our diagrams for the configurations that lit the bulb?" The sharing of ideas in both parts of the lab is an important part of the learning process and should not be skipped. Students learn not only through their personal experience, but also learn as they are forced to put words to their ideas and explain things to their peers. Hearing similar ideas expressed in other terms by peers may help students to refine and deepen their understanding of big concepts.

FIGURE 3

Complete this Circuit: *Teacher Notes*

Part 1. Lighting a Light Bulb With Only One Wire and a Battery

You and your lab partner will be given a D cell battery, a wire and a light bulb. Arrange these materials together so that the light bulb lights up. Once you have a working set-up, draw the configuration on a white board and are prepared to report your findings to the class.

Part 2. Completing a Broken Circuit Without a Wire

Solids	**Solutions**
Salt (NaCl)	Distilled Water
Sugar ($C_6H_{12}0_6$)	Tap Water
Baking Soda ($NaHCO_3$)	Salt Water
	Sugar Water
	Baking Soda Water

Before beginning, answer the following two questions:

1. Which solids and which solutions do you think will make the light bulb light?

2. What is a rationale for testing both solids and solutions?

In a 100mL beaker, place a small amount of one of the solids or solutions. Put the broken circuit in the beaker and record what happens. Repeat this step for each of the solids solutions.

When you have tested all of the solids and solutions, attempt to draw a relationship regarding what does and what does not light the bulb.

Prepare to present your results and analysis to the class.

Important!
Students must be given a 6 Volt battery in order to see the light bulb illuminate. A D-cell battery will light the bulb too weakly, or not at all, for students to notice.

Of course, some students have wrongly interpreted their experiences and teachers must help the class resolve such problems. For instance, some students have not carefully observed what part of the battery or bulb the wire is touching and draw erroneous conclusions. Rather than tell students their error, have them light the bulb with the one battery and wire. Have everyone closely observe the set-up. Rarely will students not correctly identify the problem. If they don't, ask them to carefully observe where the wire is touching. Additional testing and teacher questioning will help all students come to the desired understanding. For readers wanting additional support in teaching about circuits using batteries and bulbs, a portion of the videotape *Minds of Our Own: Can We Believe Our Eyes* (Annenberg/CPB, 1997) can be very helpful.

After helping students understand a basic circuit, students are now ready to begin the investigation of ions. Begin by providing a list of the solids and the solutions that will be used in the investigation (Figure 3). The solids and solutions that students are given to test are familiar to the students and inexpensive. Using materials that are familiar to students helps them see that the phenomena they are studying is not exclusive to the science laboratory. The two initiatory questions in the activity (Figure 3) are asked for two key reasons. The first is to get students thinking and making a prediction about what they will experience in the laboratory. The simple act of having students make a prediction often motivates them to see what will happen to determine the accuracy of their predictions. The second reason is to give the teacher an idea of what students are thinking. Knowing what students are thinking before going into the lab can be an invaluable asset as students work through the activity.

Some students believe that tap water will make the light bulb light up because there is "stuff" in the water. Other students believe that having something dissolved in the water (i.e. baking soda, salt, sugar) is enough to cause the light bulb to light up, while others see this as reason for the light bulb to not light up. The teacher can use this knowledge to ask questions specific to different students and to make sure the experience addresses their misconceptions. If a student is convinced that the tap water will light the light bulb due to the "stuff" in the water, the teacher could ask the student, "What do you think the "stuff" in the water is?" For a student who thinks that baking soda, salt and sugar will produce the same results the teacher could simply ask, "Why do you think baking soda, salt and sugar dissolved in water will produce the same result?" When asking questions the teacher needs to strive to understand the rationale behind each students' misconceptions.

Students are now directed to test the solids and solutions and record what happens. The procedure is intentionally vague, and before students are allowed to go into the laboratory a short class discussion should be held to help students think about and understand the procedure. The teacher has the critical role of helping students think through the purpose of the activity and construct the missing pieces through effective questioning. The lab instructions tell students to use a small amount of the substances provided. Ask, "What does a small amount look like?" and "What are the pros and cons of using a small amount?" The intent of these questions is for students to *think* about what they are being told to do and consider what makes sense and what doesn't make sense about the stated procedure. This creates a much more mentally engaging situation than merely having students follow step-by-step procedures. Done consistently throughout the school year, students learn the valuable laboratory and life skill of always considering the pros and cons of a situation, before making a decision.

Throughout this activity students will be provided only one beaker. Contamination is a constant risk throughout the activity, and again questioning is key to helping students *think* about and avoid this problem. Ask students what are the pros and cons of having only one beaker to use. Pros and cons do exist, but wait-time and encouraging non-verbal behaviors are required to draw these out. "Contamination" is often offered as a disadvantage, but if it isn't ask, "What problem might occur as you use the same beaker for each different substance?" After this discussion, ask "What precautions are needed to avoid contamination?" By asking students what precautions they need to take because they will only receive one beaker, students will have thought about and understand the rationale for washing each piece of equipment.

Finally and most importantly before allowing students into the laboratory, students should make a list of all of the safety precautions they need to take while they are in the lab. Both students and teachers can become complacent about safety precautions as the school year progresses. By asking questions that draw students' attention to safety issues in each and every lab experience, students and teachers are reminded of the importance of safe practices. All of the questions asked during this discussion require students to critically think about the directions. The discussion also forces students to communicate their ideas and to show respect for themselves and others which are goals that all educators have for students.

As students are working through the laboratory, the teacher should walk around the classroom watching and listening to what each group of students is doing. The teacher should be ready to pose thought-provoking questions using the students' results, like:

> Why do you think the light bulb went on when it was in ________ but not ________?"
> What do the substances that light the light bulb have in common?
> What do the substances that do not light the light bulb have in common?

These questions not only cause students to think, but give the teacher more insight into where students are struggling or understanding during the laboratory experience.

The final aspect of this lab requires students to use white boards or overhead transparencies in presenting to the class their findings about what causes the light bulb to light. This presentation is done not only to promote several important cognitive and social goals for students, but also to accurately portray the nature of science. In this final presentation of results students will together to create a flow chart outlining a set of experimental procedures used to determine what solutions and solids caused the light bulb to light. Students will need to reflect upon how they proceeded through the lab to generate and interpret data. Careful reflection is necessary to provide clear instructions that someone else could use to recreate the laboratory. This is another key component of the activity for a variety of reasons. First, it compels students to reflect upon the outcome of their laboratory. Secondly, it mimics the science community. Scientists provide their procedure so that their colleagues can determine whether they can recreate the results. If students need to go back into the laboratory to refine their results, time should be provided for that task.

From this point, the laboratory activity can go in multiple directions. Teachers can bring in 'unknowns' for the students to test. These unknown samples can be solids and solutions that are less familiar to students, but that further illustrate the concept that ionic solutions will conduct a current. Examples of possible solids and solutions can be found in unmodified versions of this activity. Teachers should be aware that many of these solids and solutions require additional safety precautions that are not discussed in this article.

The Role of the Teacher

As addressed earlier, the teacher's role throughout this entire experience is crucial. If left to fend for themselves, the students will not reach most of the desired results on their own. This activity, like most all effective inquiry activities that promote a deep understanding of fundamental science ideas, requires key teacher behaviors and interactions.

First, when asking questions, the teacher should ask a thought-provoking question, acknowledge students' responses, and then ask another question that relates back to the answer that was provided by one of the students (Penick, Crow & Bonnstetter 1996). Teachers benefit from asking questions in this manner because they can determine what students are thinking. If a teacher asked yes/no questions or questions that require little thought, the teacher would not have a clear understanding of what students are thinking. By following up and using students' ideas, the teacher can clarify what students are thinking and show an appreciation for student input in the classroom.

A teacher can ask effective questions, but if he or she does not use proper wait time or positive nonverbals (such as eye contact, enthusiasm and positive facial expressions) the questions may be asked in vain. After asking a question, the teacher should wait a minimum of 4 seconds before talking again (Rowe, 1986). This pause allows students time to think about the question encourages them to formulate and provide a response. Additionally, teachers are often too quick to talk after one student has offered an answer. If teachers wait, other students will often offer solutions to the question, or elaborate on prior ideas. This secondary wait time not only gives the teacher a deeper insight into what more of the class is thinking, but also gives the teacher time to think of the next question to ask students. Waiting also helps to encourage more students to talk, which helps students develop their communication skills--another goal teachers have for students.

Final Thoughts

This activity serves as an excellent introduction into ions and ionic compounds. Specialized equipment and materials should *not* be avoided in the lab, but should be carefully scaffolded to so that students understand what the equipment is doing and so that it does not interfere with understanding the targeted science concepts. Care needs to be taken so that students understand the materials, and their implications on the results. Such care will help students develop a deeper understanding of the content that is being addressed, which will serve as a strong foundation for future concepts.

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