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Collin Reichert
Ames Middle School, Ames, Iowa

Curtis Titter
Arthur Williams Middle School, Jesup, Georgia

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All Bottled Up

AN INQUIRY ACTIVITY USING BOTTLES TO TEACH THE EFFECT OF WATER TEMPERATURE ON DISSOLVED GAS

Bottle photo by Nathan Bauer, Earth imagery by NASA; Graphic Work by Joe Taylor

Collin Reichert, Ames Middle School, Ames, Iowa
Curtis Titter, Arthur Williams Middle School, Jesup, Georgia

ABSTRACT: This article describes an inquiry activity that promotes an accurate and deep understanding of key components of the carbon cycle, namely the exchange of carbon dioxide (CO_2) gas between the atmosphere and the ocean, and how temperature affects this exchange. The crucial role of the teacher during this activity is described, including key questions and interactions that help students arrive at deep and robust understandings of the carbon cycle and nature of science ideas. *This article promotes High School National Science Education Content Standards A, B, D, and G, Iowa Core Curriculum 1 and 3, and Iowa Teaching Standards 1, 2, 3, and 5.*

A deep and robust understanding of climate change requires an application of many Earth science ideas including interactions among tectonic events, solar inputs, planetary orbits, ocean circulation, volcanic activity, glaciers, vegetation, and the carbon cycle, all of which can have significant effects on temperature and precipitation patterns (ESLI, 2011). Students must realize the intricate connections between Earth's lithosphere, atmosphere, hydrosphere, biosphere, and how the movement of matter between these “reservoirs” is driven by internal and external sources of energy. An understanding of these connections, and the impact of human activities on them, is best promoted when the essence of inquiry is maintained and teaching is focused on questions that can be answered by reasoning processes linked to direct observations of phenomena (NRC, 1996). Teaching climate change in particular also offers educators a tremendous opportunity to explicitly teach the nature of science and the role of science in society.

The activity described in this article is best situated during the second semester of a two-semester Earth science course, after students have developed an accurate understanding of the nature of Earth science, geologic time, and plate tectonics. In our classes, this activity follows a unit on weather/climate and the greenhouse effect, and initiates our unit on ocean acidification. This activity is designed to teach students the role temperature plays in water's ability to hold dissolved gasses. Later instruction builds the idea of exchange of CO_2 between the atmosphere and the ocean, particularly the release of CO_2 in warm ocean water and incorporation of CO_2 in cold ocean water.

The Teacher's Crucial Role

Highly effective teachers exhibit consistent behaviors with respect to the types of questions they ask, how they react to student responses, and how student ideas are incorporated into class discussions. Throughout the activity presented below, we provide thought-provoking, open-ended questions that permit us to access students' prior knowledge and preconceptions, and then present additional questions that help students make links leading to desired understandings (Penick, Crow, Bonnsetter, 1996; Elstgeest, 1985). When these types of questions are asked, students need time to think before putting forth a response, therefore wait-time I and II are both crucial for thoughtful cognitive processing (Rowe, 1986). From the teacher's perspective, wait-time promotes appropriately paced and more thoughtful instruction, thus providing needed time to formatively assess students thinking and formulate effective follow-up questions. Exhibiting inviting non-verbal behaviors (e.g. smiling, looking expectantly, leaning forward, and using equality of status) while waiting for student responses is essential (Goodboy, Weber, & Bolkan, 2009; Penick & Bonnstetter, 1993). For many students, putting forth a response can be a risky proposition. Listening carefully to students (without rejecting ideas), responding by asking students to elaborate and/or clarify their ideas, and incorporating students' ideas into class discussion make clear their ideas are valued (Penick, Crow, & Bonnstetter, 1996). We work to interact with students in this manner to convey that students' ideas are important, and thus promote more student mental engagement.

Introducing the Activity

Effectively planning instructional activities demands extensive attention to how people learn. Effective planning considers, among other things, students' prior knowledge and potential misconceptions, the developmental appropriateness of content, and ways to promote social interaction among students. To help students better understand abstract science ideas such as the carbon cycle, concrete examples should be utilized which increase in complexity and follow a multi-step logical flow (NRC, 1996).

To initiate the activity, we establish students' attention by saying, with exciting voice intonation, “Listen up closely, I have something fascinating to share with you.” We then open a bottle of soda. With a puzzled look and appropriate wait time, we ask students what might account for the sound they heard. After this first experience, we want to further push student thinking by having them compare two soda bottles (students are unaware that one bottle is cold and the other warm). Under normal conditions, the temperature difference of the two bottles can be readily discerned through the condensation of water vapor on the cold bottle. To mitigate the problem of condensation, we advise keeping one bottle in hot water and the other in ice water (with students unable to see this). If we remove the bottles from the water just before initiating the activity, both bottles will be wet on the outside. Also, we remove the labels from the bottles so students can better make detailed observations.

We inform students they need to be paying close attention for this is the phenomenon they are going to set about trying to explain. Utilizing thought-provoking, open-ended questions is crucial for accessing students' thinking, thus establishing a foundation for knowledge to be built upon. Therefore, before opening the first (cold) bottle of soda, students are asked questions such as:

- “What are some observations you might make?”
- “What do you expect to happen when I open this bottle of soda?”

Asking prediction questions mentally engages students and reduces the potential for classroom management issues and makes more likely that students will closely observe the demonstration. We open the cold bottle of soda first and have students record their observations. Upon opening the bottle, students will likely notice gas bubbles forming, a “hissing” sound, and gas bubbles moving from the bottom of the bottle to the top. Because students may attend only to the sound made, be prepared to ask questions such as

- “What changes, if any, did you see?”
- “What else do you observe?”

Once observations are recorded, we then open the warm bottle of soda and again students record their observations.

If students ask to directly touch the two bottles, we choose to address how scientists must often investigate phenomena that they cannot directly touch. If students don't raise the issue of wanting to examine the bottles directly we raise this nature of science idea by saying: “I'm perplexed by the fact nobody wanted to directly touch the bottles of soda.” We then ask students a series of questions such as the following:

- “To what extent are scientists such as astronomers and seismologists able to directly touch the natural phenomena they investigate?”
- “How can astronomers and seismologists figure out the structure of a star or the structure of the earth without ever going to a star or ever being able to go through the earth?
- “If we are not able to touch the bottles of soda, how might we still test our ideas to account for the different observations made?”

With the warm bottle of soda, students often notice a louder sound and more violent bubbles (and sometimes an eruption!). Following the recording of observations we have students discuss in small groups how they might account for what they heard and saw. During this short sharing of ideas, we circulate around the room listening to students' ideas and, if needed, asking questions that seek elaboration of their initial ideas.

The primary intent of our activity is to investigate the effects of temperature on dissolved gas. If students do not bring this up on their own, the following question could be asked,

- "What might be the benefits of storing your opened bottle of soda in the refrigerator instead of on your counter?"

If students are still having difficulties the following questions could be asked:

- "Over the course of a few hours, what might occur to the soda if the lid was left off?"
  Anticipated student response: "The soda goes flat."
- "What do you mean by 'flat'?"
- "What could account for the soda becoming flat?"
  Anticipated student response: "The bubbles escaped."
- "Where do the bubbles go?"
  Anticipated student response: "The air."
- "How do you try to prevent the soda from going 'flat'?"
  Anticipated student responses: "Put a lid on it" or "put it in the refrigerator."
- "Why might putting soda in the refrigerator prevent the soda from going 'flat'?"
  Anticipated student response: "The cold must have something to do with it."

At some point in the investigation we draw students' attention to nature of science ideas such as creativity and the limitations of science. We ask questions such as:

- "What roles do creativity and imagination play in our efforts to investigate what we may not be able to directly observe?"
- "How does our investigation of the soda bottles without touching them help us understand that scientists are creative and imaginative in their investigations of natural phenomena?"

Once we have drawn students' attention to focus on the temperature, we guide students to the desired investigations regarding the impact of temperature on dissolved gas. The following types of comments and questions are used to help guide students:

- "Many people suggested the idea of temperature having an effect on how much gas escaped the bottles. What prior experiences do you have to support this claim?"
- "Although you've proposed many interesting aspects we could investigate about the soda bottles, people most typically believe colder temperatures keep things carbonated. Because this idea is so common, we will investigate this a bit further. We have limited materials, and these are the only materials you can use: carbonated water--What is carbonated water?--hot water, ice water, 2 bowls and 2 cups per group. I want you to investigate how temperature affects the dissolved gas in carbonated water."

At this point, we present the materials to students along with expectations on how they should be acquired and used. This is necessary to prevent down-time from occurring when students obtain their materials. Proactively addressing how materials are to be acquired, safely used, and returned significantly reduces classroom management problems. We also expect students to clean up after themselves and by this point in the semester have established routines for clean-up and other routine aspects of laboratory work. We then continue with the following instructions:

- "Your task, in the next 10-15 minutes, is to devise a test or tests examining the relationship between temperature and the ability of water to "hold" dissolved gas. Before you can actually carry out your tests they must first be approved, so no testing without first receiving explicit approval from me.

Rather than end with "Do you have any questions", we ask, "What questions do you have?" and wait expectantly. This change in wording may appear trivial, but we have found that students ask far more questions with this change.

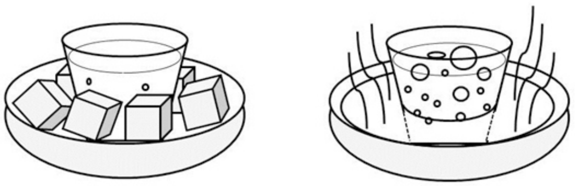
Students, with rare exception, are quick to propose testing soda at different temperatures. However, some students may want to place ice directly in the carbonated water to lower its temperature. In this situation we would ask students the following sequence of questions:

- "What are advantages to placing ice directly in your carbonated water?
  Common response: "That would cool the carbonated water."
- "What will happen to the ice as it cools the carbonated water?
  Common response: "It will melt."
- "What might be problematic about this...where will that melted ice go?
- "How might additional water in your soda interfere in your test?
- "How will this create a new variable between your two set-ups?

After conversations such as above, students typically design a set up such as in Figure 1. Depending on past experience, students might need help setting up ice water and hot water baths. Students sometimes struggle with how to measure the difference in gas that escapes from the different temperatures of soda. While students typically want to quantify these numbers somehow, we introduce them to the value in qualitative differences. We ask,

- “What will you look for to decide which temperature “holds” more gas?” or
- “How could you describe the differences in the warm and cold soda?”

FIGURE 1
Sample set up for (left) icy bath and (right) heated bath.



Graphic work by Curtis Titter and Collin Reichert

To encourage students to make their thinking more explicit we ask,

- “How did the bubbles in the warm carbonated water compare to the bubbles in the cold carbonated water?”

Once students note that there were fewer bubbles in the cold water we ask students to use this observation to make claims about temperature by asking,

- “What does temperature do to water's ability to retain a dissolved gas?”

When students claim that decreased temperature seems to increase water's ability to “hold” gas, we ask,

- “What evidence do we have to support the idea that warmer water cannot hold as much dissolved gas as cold water?”

While this question might seem redundant, asking students to explain their thinking again will provide additional insight to student thinking. Students usually have little problem concluding that temperature and amount of dissolved gas are inversely related.

We then tell students that what they have determined is similar to the behavior of most gases in liquids. That is, all else being equal, cold liquid will hold more dissolved gas than the same liquid at a warmer temperature. When we have sufficient evidence that students understand this general principle, we seek to determine how well they can apply the knowledge generated in this activity to a novel situation. We present students with a video of a fish on a hot day swimming at the surface of a lake seemingly inhaling air. We ask students to speculate on why this fish is behaving in such a manner and eventually build to the idea that there is less dissolved oxygen in the water when the lake water is warm.

We use this lake example as a way to help students make connections to broader environmental issues such as global warming. We ask questions such as:

- “We know that the Earth and the oceans have been warming. What do you think will eventually happen to carbon dioxide dissolved in the oceans as ocean temperatures increases?”
- “If carbon dioxide in the atmosphere contributes to global warming, how might the carbon dioxide leaving the oceans affect global warming?”
- “Why might increasing ocean temperatures and carbon dioxide escaping from the oceans be especially problematic for global temperatures?”

Discussion

The activity described in this article is largely modeled on the learning cycle model (Abraham, 1997; Colburn & Clough, 1997). We begin the activity with an everyday experience – opening a bottle of soda. This example was not selected merely for entertainment, but in a deliberate effort to provide students a concrete experience, moreover one they will encounter regularly for the rest of their lives. Figure 2 illustrates how we moved from this beginning concrete everyday experience to more abstract thinking, back to concrete experiences, and then continued to bridge abstractions with concrete experiences as we moved to the desired abstract generalization regarding the effect of water temperature on the amount of dissolved gas. Because learning is enhanced beginning with concrete experiences and using those to teach abstract concepts (Karplus, 1977), we chose this activity to begin our unit on ocean acidification. Once students understand the relationship between temperature and dissolved carbon dioxide in the oceans, they will be better prepared to understand the importance of ocean acidification and its links to carbon dioxide levels.

In this activity, learners generate ideas as they try to make sense of experiences. Prompting students to think about scientific content in everyday experiences, such as opening soda bottles, leads to a very large number of experiences in which students think about science content outside of the classroom. Encouraging active mental engagement and connections to other experiences greatly increases the likelihood students will internalize science ideas and develop deep and robust understanding of science content as a multitude of experiences are provided to remind students of the science idea.

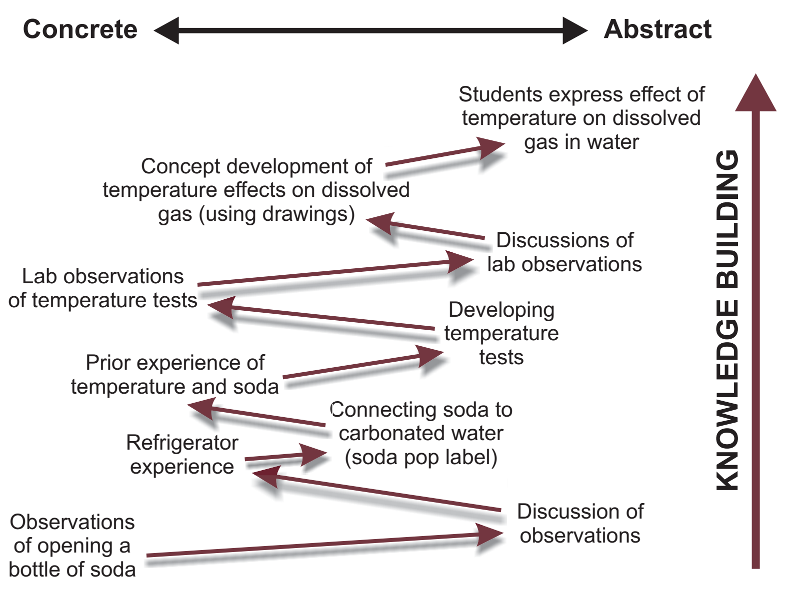
Use of concrete representations and explicit connections to students' experiences will help scaffold student learning. Additionally, student language needs must be considered during instruction. This consideration provides the rationale for the repeated class discussions, written recordings along with other symbols (e.g., drawings) throughout the course of the activity (Vygotsky, 1978; Dixon-Krauss, 1996).

Conclusion

This activity provides the concrete experiences that we use to help students develop the desired science concept that the amount of dissolved carbon dioxide decreases with increasing water temperature. However, the concrete experiences are not enough. The teacher's use of effective questioning, positive nonverbal communication in conjunction with wait time, and using student ideas determines the effectiveness of the experience. Interestingly, students sometimes perceive they came to understand the science content on their own, but in actuality such conceptual understanding would rarely have been achieved without the teacher intervening to help them develop the accurate science concept. Effectively teaching science through inquiry is far more demanding, but more effective (Minner, Levy & Century; 2010) and rewarding for teachers and students.

FIGURE 2

Progression of student tasks and teacher scaffolding in the modified activity. The activity begins with a concrete activity and proceeds to the abstract student objective through scaffolding questions and tasks deliberately asked by the teacher and tasks fluctuating from highly abstract (discussions) to highly concrete (lab experiences). Throughout the entire process, student knowledge of the objective slowly accumulates.



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***Collin Reichert** teaches physical science at Ames Middle School in Ames, Iowa. He was awarded the Outstanding Teaching Assistant Award through the National Association of Geoscience Teachers. Contact Collin at collinreichert@gmail.com.*

***Curtis Titter** teaches science at Arthur Williams Middle School, Jesup, Georgia. He has experience as an Environmental Educator at Rock Eagle and Jekyll Island 4-H Centers through the University of Georgia. Contact Curtis at cmtitter@gmail.com.*