Graphic by Joe Taylor

TEMPERATURE RISING

INVESTIGATING RATES OF TEMPERATURE CHANGE

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ABSTRACT: This exploratory activity, designed for secondary physical science or earth science students, investigates rates of temperature change over bodies of water and land. Students discuss temperature trends of several cities across the United States, which creates an opportunity to conduct classroom experiments to explain these trends. Students write procedures and generate data of temperature changes between areas of water and land. Students gain a valuable, concrete experience of temperature changes which in turn enables them to better understand and explain why similar cities experience vastly different temperature patterns. This activity can then serve as a basis to address the abstract concept of heat capacity. *The activity promotes National Science Education Content Standards A, B, D, and G, as well as Iowa Teaching Standards 1, 2, 3, and 5.*

Heat capacity is an abstract concept with which students often struggle to deeply understand. Too often instruction regarding heat capacity begins with an explanation of the concept followed by a few examples illustrating the concept, and then moves on to mathematical problems related to heat capacity. However, learning is enhanced when students have a concrete experience on which to anchor abstractions. The activity described here engages students with a concrete experience that readies them for the more abstract concept of heat capacity.

The activity was modified from a cookbook lab in which students follow a step-by-step procedure that did not require critical thinking, collaboration, creativity, or wrestling with the concept of heat capacity. Modifications were made that encourage students to be more creative, collaborate with peers, and critically think about phenomena related to heat capacity. Students are required to create their own procedure and apparatus for obtaining data. Throughout the activity, we address areas where student misconceptions arise and the appropriate actions to take in helping them understand the problems with their initial ideas. The teacher's role is to guide students through this exploratory activity by asking thought-provoking questions that move students toward desired ends. This activity requires approximately three 50-minute class periods. While not addressed in this article, we recommend transitioning from the instructional sequence described here into further concept development of heat capacity.

Day 1 - Instructional Sequence

Begin by writing the following cities on the board: Columbus, Ohio; Fort Bragg, California; Denver, Colorado; Lincoln, Nebraska; New York City, New York. Help students connect the geographic similarities between these cities. Use guiding questions to help students to come to the idea of marking these cities on a map. Sample questions include

- "What are similarities in the geography of the cities listed on the board?"
- "With which city's geography are you least familiar?"
- "Where within the United States is each city located?

The map (Figure 1) is a concrete representation that allows students to actually see where these cities are geographically. The objective here is to help students see where the cities are geographically in the United States, in particular that these cities have approximately the same latitude (40^{o} N).

Next, students should begin thinking about the temperature differences experienced between the five cities. Ask,

- "We know that these cities are each near 40^{o}N latitude, but what temperatures do these cities experience?"

After students note their ideas, place representative late spring to early fall high and low temperatures for each city on the board. Table 1 shows the high and low temperatures for May 20th, 2010. Note that all locations experienced sunny weather. Ask

- "What interesting things do you notice about these temperatures?"

Really sell this question with inquisitive nonverbal behaviors such as a genuinely interested yet slightly puzzled look. Make eye contact with several students and use wait-time I and II to encourage all to participate. If necessary, ask questions such as

- "How are the temperatures similar?"
- "How are they different?"

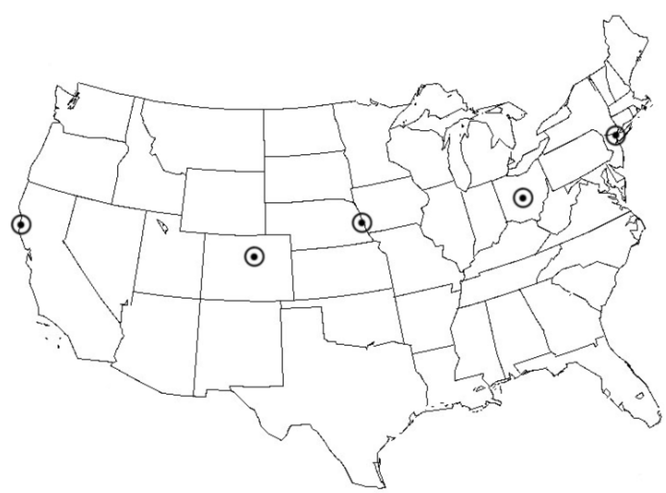
Here, the goal is to help students notice that cities along large bodies of water experience cooler temperatures and a less severe fluctuation in temperature. When students come to this tentative pattern, ask,

- "To be sure of this, what should we do to increase the amount of evidence regarding this initial idea?"

Students may want to look at the temperatures of different cities, both near and away large bodies of water. Depending on student understanding, the teacher should make the decision to continue or incorporate more cities. If students do not make the connection between proximity of a location to large bodies of water, additional questions will be needed. Such questions include

- "The cities with the narrowest range in temperature share what common features?"
- "What might account for such dramatic fluctuations among the inland cities?"

FIGURE 1
Sample Map with Marked City Locations.



Students should focus on the factors that account for the greater fluctuations in temperature among inland cities.

The next objective is to help students connect the pattern they have inferred to the important insight that land heats and cools faster than water. This will provide a significant scaffold to the more abstract scientific idea of heat capacity.

TABLE 1
High and Low Temperatures.

City	*High Temp (^{o} F)*	*Low Temp (^{o} F)*
New York, NY	*74*	*60*
Columbus, OH	*74*	*44*
Lincoln, NE	*82*	*62*
Denver, CO	*83*	*51*
Fort Bragg, CA	*54*	*41*

Once students are confident that landmasses near large bodies of water warm and cool more slowly, it's time to gather more data. We begin by saying, "Keep in mind the pattern you have inferred: land far away from large bodies of water warm faster as well as cool faster than cities near a large body of water."

We follow up this statement by asking

- "How might we gather more evidence to support our claim that water moderates the temperature of cities near large bodies of water?"

Usually, students will want to look up more temperatures of cities.

- "While all these are fine ideas, what can we do to test this naturally occurring phenomenon in our classroom?"

Place extra emphasis on the word *test*, for we want students to realize that it is time for an experiment. Students will come up with many ideas, some beyond the capabilities of the classroom. Listing all students' ideas on the board is important so that after all ideas have been generated, students can be asked to assess the pros and cons of each idea. The pros and cons to the suggested ideas are determined, in part, by the materials available for testing.

Now is the time to introduce the materials the students can access for this experiment: bowls, dry sand, water, heat lamps, buret clamps, ring stands, thermometers, timers, and paper. Ask

- "Given that we are limited to the following materials, which of your ideas are most viable? Discuss this with your partner."

During this time, we walk from group to group listening to the different ideas. We allow around a minute for these ideas to be narrowed down.

Next, address any safety issues associated with the materials. For example

- "We've used all of these tools in the past except for the heat lamp. The previous safety procedures will still be in effect. However, what are some important safety issues associated with the heat lamp?"

After several student answers and appropriate teacher responses ask

- "How will we prevent any injuries from occurring related to the heat lamp?"

The most significant issue is an electrical lamp next to water. Ensure the lamps are well supported and cannot be knocked over. Also ensure they are plugged into a ground-fault interrupter. We have students unplug the lamp before taking temperatures. This step not only reduces safety concerns, but prevents the lamp from heating the thermometer while reading the temperatures. We also note that the materials that students heat can get very hot and they need to be careful when taking their measurements. When reiterating safety concerns, make sure all students are looking and listening to you. Even so, constantly monitoring the classroom is essential during this activity to ensure students are following appropriate safety practices.

The students are now ready to create their procedure. Their goal for tomorrow is to have their procedure ready to begin their testing.

Day 2 - Gathering Data

Remind students of the safety protocol associated with the heat lamp and the other materials. The heat lamp can cause serious harm if safety procedures are not followed. Students are allotted the entire class period to determine how they will conduct their testing, get instructor approval, and then conduct their tests. Ensure students clearly understand that they may not begin any testing until their procedure has been approved. As you listen to students' proposed procedures, ask questions to ensure both conceptual and safety issues are addressed. Walk around listening to and observing students as they think and work. Constantly watch for safety concerns, quickly address any potential classroom management issues, and ask questions that guide students to a deeper understanding of an appropriate set up and data collection. Questions should help both the teacher and the student understand their reasoning for the many decisions they make. Having students make predictions about what they expect to get for data also illuminates students' thinking.

As students are setting up, ask groups

- "Where will you place the thermometer?"
- "Why should it be placed there?"
- "What would happen if we put it in a different location?"
- "How close should we put the heat lamp?"
- "Why not too far away?"

The main objective is to understand the students' reasoning, get them to verbalize their understanding, and encourage them to critically think about the decisions they have made. Ask how the students will be obtaining their temperatures and ask,

- "What are the pros and cons of obtaining a temperature with the heat lamp on?"

Here, we revisit the notion that obtaining temperatures with the heat lamp off is best.

As students are performing their experiment, always scan the classroom. Minimizing off-task behavior is an important safety measure. When students notice different phenomena, ask questions that poke and prod at important ideas. For example, students quickly realize that water temperature does not change much compared to the sand.

Help students connect this experience by asking

- "Where else have you witnessed this before?"

Students often respond with sand at a beach is hot when the water is cool. We also encourage students to connect their observations to the city temperature data from yesterday.

Students are allotted the entire class period to finish experimenting. If students seem to be finishing early, we ask them how they might gain greater confidence in their observations or what new tests they might conduct to better understand the phenomenon. As class comes to an end, we provide only 3-5 minutes for students to properly clean their area and return all materials to the appropriate location. This is easily accomplished if students have previously been taught expectations for clean-up, and how to accomplish those in just a few minutes. If some groups finish early, they are to begin analyzing their results. The following questions will compel them to think about the process of analyzing their data.

- "How are you going to organize and analyze your data?"
- "Why is organizing data important?"
- "What decisions that you made during this activity are similar to what authentic scientists make?"

Day 3 - Analysis and Discussion

Today, all groups are given ten to fifteen minutes to finish organizing and analyzing their results. As groups are working, walk amongst them listening and observing. Add comments that encourage students to critically think about their actions.

- "How have you organized your data?"
- "Why did you choose that way to organize your data?"
- "What are some other ways you could have organized your data?"

Students often find it challenging to organize and analyze their data in a clear fashion so others can understand. Some groups will have made a chart to compare the temperatures, while others will graph them on paper. No one correct way to analyze data exists, but some ways turn out to work better than others.

As groups begin to finish, now discuss as a class the ways in which the groups analyzed their results.

- "How did you analyze the data that you collected?"

Be ready to respond with questions that ask why and how they analyzed their data. Often, students will have little idea why or how they analyzed their data and simply summarize their interpretations or conclusions. Write these data analysis methods on the board and discuss the pros and cons of each. Graphs provide students with a physical representation of the data. Students can easily see how the temperatures differ among mediums. Charts allow students to compare temperatures side by side, lessening the chance for misreading.

During these discussions of data interpretation, we reiterate the notion that data must be interpreted – data never tell scientists their meaning. Students often have the misconception that "data tell" or "data show" when in fact data do neither. Scientists need to make sense of the data. They interpret data in a way that they can understand and apply it. If you choose to expound on this topic with your students, a sample question we have used is

- "How will your analysis model the idea that data don't tell scientists what to think, but that scientists must interpret meaning from data?"

Once students have shared their data analysis methods, refer back to the table of cities and their respective temperatures. Ask questions regarding this information.

- "How does our experiment reflect, if it does at all, the information we have in this table?"

Give them a few more cities and have them predict how significant the range in high and low temperature might be. Be sure to apply what the students have found in their experiment back to the previous cities and incorporate new cities. Linking their new understanding to previous cities encourages students to fit knowledge in with prior learning. Extensions to new cities encourages students to apply their new learning and think more deeply about their conclusions.

After applying what the students have found through the experiment, begin a discussion with questions regarding what they interpreted from their data.

- "Which material heated faster?"
- "What is your evidence?"
- "Why are summertime temperatures more moderate near large bodies of water than temperatures found inland?"
- "Why would it be wise to bring a sweater on a trip to a desert?"

Students need to understand the concept that temperatures near large bodies of water are generally cooler and fluctuate less than temperatures inland. As a last question for students to wrestle with ask

- "What are some possible explanations for why one material heated and cooled faster than the other?"

Depending on the amount of time left in the period, you may choose to have students discuss this for the rest of the period or move into more abstract ideas such as heat capacity.

Conclusion

Teachers may have considerable returns on time invested when modifying step-by-step, cookbook type activities towards more inquiry-based activities. Having students generate their own procedures during an investigation encourages students to be mentally engaged in what they are doing – the hallmark of what is required for developing deep understanding. Research supports numerous benefits of learner-centered instruction including: more on task behavior, less copying, less disruptive behaviors, and overall increased student engagement (Shymansky & Penick, 1981).

The teacher's role during this process is to support the students' progress through the use of carefully crafted questions that point students in fruitful directions. Without such carefully crafted interaction, students will rarely come to scientifically accepted ideas about the natural world. This inquiry-based exploratory activity promotes decision-making skills, critical thinking, collaboration, and creativity, and provides a concrete experience needed to scaffold students to the more abstract concept of heat capacity.

References

Shymansky, J. and Penick, J. (1981). Teacher behavior does make a difference in hands-on science classrooms. *School Science and Mathematics*, 81, 412-422.

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