LESSON PLAN: MEASURING THE EFFECTIVENESS OF SUNSHADES

In the activity at the heart of this lesson, students will construct a simple device to examine how substances can be protected from sunlight. They place an ice-water mixture in a coffee can and use a sunshade to protect the contents from sunlight. Based on the amount of ice that melts during the experiment (and their understanding that this is a way to measure how much heat energy the ice-water mixture receives), the effectiveness of their shade can be estimated. For a description of the experiment setup, see Figure S1 in Student Worksheet 1.

The experiment is done over two or three days. During the first day, the basic concepts of heat transfer and phase change are discussed, and the students form groups to design the sunshade to be used in their experiment. In the second day, the experiment is performed. In the third day, the results are analyzed. If there is sufficient time in the second day, the lesson can also be completed then.

The experiment serves two purposes: First, it is a simple way to test the effectiveness of a sunshade designed by the students. Second, the basic setup for the experiment is a simple way to measure the desired property – the effectiveness of the sunshade. But it also is intentionally designed to have some sources of error (such as heat conduction from warm air and sunlight striking and heating up the sides of the can, not just the top). While the errors are controlled in the experiment and the results about the effectiveness of the sunshades are valid, the students are also encouraged to think of ways to improve the design of the experiment to eliminate some of the sources of errors. (Sharing of data among different classes is also strongly encouraged.)

Materials

Per group of 3

- 2 11.5 oz. coffee cans
- Bucket to hold ice-water mixture
- Ice cubes or small chunks of ice (enough to fill the bucket and keep water cold)
- Water (enough to fill the bucket)
- Thermometer
- Shielding materials (each group brings their own)
- Stopwatch
- Stir stick (any stick that can reach the bottom of the bucket will do)
- Optional: Strainer
- Tape
- Standard ruler (30.5 cm, 12 inches)
- Calculator
- Protractor

Per class

- Scale capable of measuring at least 500 grams (one per class will do, but one per group is better)

Preparation

- Make enough copies of student worksheets and MESSENGER Information Sheet for each student to have one of each.

Points to consider in preparation of the experiment to ensure maximum results:

- It is best to conduct this experiment on a sunny day as close to noon as possible. This way the Sun's rays come more directly down on top of the cans and the energy received from the desired direction is maximized. The cooler the temperature is during the day, the smaller the errors due to heat conduction from the air. If you want to stress error control, you may want to conduct the experiment on a warm day. If you want to stress the shade effectiveness, you may want to perform the experiment on a cool (but sunny) day or in a cool classroom on a sunny day. If it is possible for students to choose at which time of the day to perform the experiment, you may encourage them to make the choice themselves.
- It is strongly encouraged that the students share their experiment data among different classes. The larger the data set on the variations in the experiment (time of day, angle of the sunlight striking the can, etc.), the better the students can understand the various sources of errors in the experiment and think of ways to eliminate them. If you do not have several classes with whom you can perform the experiment yourself, you may want to combine your efforts with another teacher.

Warm-up & Pre-assessment

1. Ask students to define temperature. Explain it to them in terms of the vibration of atoms and molecules.

2. Ask students the three basic ways in which heat and energy can be transferred. Ask students to think of examples of these ways, and record their answers. Group their answers into three categories, "Conduction," "Convection," and "Radiation." In each category, ask the students for ways in which each can be prevented (or insulated).

3. Focus on radiative heat transfer, especially sunlight. Ask students why we would want to prevent radiation, and which types need to be blocked (in particular, sunlight). Ask the students to list a few practical ways in which we can reduce or prevent exposure to radiation. Discuss active (cooling by doing work; refridgerators) versus passive (cooling without doing work; sunshades) cooling, and ask the students what they think are the advantages of each. (Be sure that cost efficiency is mentioned.)

4. Give the students the scenario in which they want to block as much sunlight as possible in order to prevent ice water from heating. Ask the students what (inexpensive) materials could be used to block the sunlight. Ask the students for ways in which the effectiveness of the materials can be tested. They may mention that they can take the temperature of the water to see how much energy has seeped through the shade, or they can add ice to the system and see how much melts.

5. Ask the students how they could take the information (such as how much ice melts) and come up with a specific amount of energy entering the system. Discuss the phase changes of water, and the idea of latent heat. Explain that a similar property, specific heat, relates to increasing the temperature of a substance without changing its phase. Discuss also the heating curve of water, and the meaning of the plateaus. Tell them that they will use this information to calculate the effectiveness of the sunshades they will design.

Procedures

Day 1: Shade Design (20-30 min)

1. Place students into groups of three. Hand out Student Worksheet 1, and briefly describe the setup of the experiment. Give students the rest of the class period to discuss and design the sunshade they will use in the experiment. Encourage them also to think of what time of the day they would like to perform the experiment (if it is possible for them to choose the time).

2. Remind the students that they need to build the shade as inexpensively as possible. The suggested cost cap is $5 but you may want to modify it or eliminate it altogether. Remind the students that they must fill out the design details segment in Worksheet 1 before building the shade in the next class, and that they will have 10 minutes to build their shades.

3. At the end of the class, remind the students to buy the materials (or bring them from home), keep the receipts, and bring everything to the next class, when the experiment will be performed.

> **Teaching Tip**
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> If you do not want your students to have to pay for their materials, you may supply the materials yourself. Keep in mind, though, that they will be calculating the cost of their shades, so you need to provide a list of your material costs.

Day 2: Activity (45 min)

1. Have the students gather in their groups and assemble the shades. Allow a maximum of 10 minutes for assembly of the shades.

2. Have the students follow the instructions in Student Worksheet 2 to prepare and conduct the experiment.

3. Make sure the students are preparing two cans – one for control, one for the shade test.

4. While the students are waiting for ice to melt in their experiment devices, they should calculate the angle of the Sun in the sky and measure the angle of their devices from horizontal. Be sure that they bring a calculator with them to the experiment site to do this. If there is time, they could also begin working on the additional worksheets, or read the MESSENGER Information Sheet. You can also suggest to the students to discuss within their group heat transfer and what is happening to the ice-water mixture during the experiment. The students will consider these issues further in analyzing their results.

Teaching Tip

It is ideal to have the students start and stop their experiments at the same time, especially if they are doing the experiment outside. This way all of your students will be in the same location and will be easier to monitor. However, if you only have one scale for the entire class, it may be beneficial to have them start and finish in succession so that they do not have to wait to use the scale. If the students can weigh their ice immediately before and after it is put in the Sun, this ensures that the ice melts as a result of being exposed to the Sun, and not being exposed to warm air. You can do the weighing in succession by having Group One weigh their cans first (with and without ice), then move on to expose their device to sunlight (and start their stopwatch), then have Group Two weigh their cans, begin the experiment, etc. At the end of the experiment, Group One can stop the stopwatch, and weigh their ice first, and then Group Two does the same, etc.

Day 3: Analysis (45 min)

1. Have the students share the data on their experiments with other groups. If you had different classes perform the experiment, share the other classes' data.

2. Have the students perform their analysis in Student Worksheets 2-3. This can also be given as homework once the students have the data from the other classes.

Discussion & Reflection

1. Discuss results with students. Was it what they expected, what was their final cost-efficiency (expressed in terms of the percentage of energy blocked by the sunshade versus the cost of the sunshade, %/$, on Page 4 of Student Worksheet 2), whose design was the most cost-efficient, what materials did they use, etc.

2. Remind the students of the heat curve of water, and ask how that is important to the experiment. How would the experiment be affected if phase changes did not occur this way?

3. Discuss with students the possible sources of error in the setup of the experiment and modifications they may have made for the setup on Student Worksheet 2. If they want to re-do their experiments, encourage them to do so. Later they can compare whether their cost-efficiency improved as a result. (Since a control can is used in both cases to take errors into account, the change should not be significant if the sunshade design is efficient.) Discuss the importance of understanding sources of errors in scientific experiments and the need to improve designs and repeat experiments as errors are discovered.

4. Remind the students of the idea of passive versus active cooling, and relate it to the concept of shadows. Discuss with students the idea of shadows creating night-time on planets, and the resulting change in temperature between night and day. Discuss how atmospheres play a role in distributing and balancing night and day temperatures.

5. Discuss the MESSENGER mission to Mercury and why it needs a sunshade. Hand out the MESSENGER Information Sheet (if you have not done so already). You can have the students consider the MESSENGER mission in greater detail by giving them an Internet research project to examine the passive cooling methods used by the MESSENGER mission designers. You can instruct the students to pay special attention to the design of the sunshade and what kind of materials are used in its construction, as well as what is known about the possibility of ice in the shaded craters in Mercury's polar regions.

Lesson Adaptations

Constrain the parameters of the experiment in the activity further by limiting the total weight of the experiment device (coffee can, shade, and whatever modifications the students make to the basic setup).

Extensions

- Have the students design actual heat shields that could be used in NASA missions to hot environments. They can research the materials and designs already in use and come up with their own. They can figure out ways to minimize the cost for these shields based on their research.

- The Student Challenge Worksheet examines the process of ice melting to water in the experiment in terms of entropy, including a calculus-based mathematical discussion of it. Even though a comprehensive discussion of entropy would be more appropriate in college, you may want to challenge at least some of your students to become acquainted with the concept.

Curriculum Connections

- *Physics:* Have students research the more exotic phases of matter (which only occur at very high or low temperatures): plasmas, superfluids, superconductors, Bose-Einstein condensates, and quark-gluon plasmas.
- *Chemistry:* Have students find out how and why water behaves differently than most materials when it changes physical states. (For example, water expands as it freezes, contrary to other liquids.) They can discuss the structure of the water molecule and how it changes when heat is added or removed.
- *Life Science:* Students can research the effects of water's structure on life. For example, if water did not expand as it freezes, ice would not float on top of liquid water due to their relative densities. This would have a major impact on anything living in lakes that have their surfaces freeze in the winter. Also, students can discuss why scientists think that liquid water is essential to life and why astronomers looking for life elsewhere think they must first find liquid water.

Closing Discussion

Remind students that by having learned about basic properties of heat and energy transfer, they are now able to design ways to keep items comfortable in excess sunlight (or other hot environments). They also are able to recognize that scientific experiments may sometimes have sources of error resulting in a need to modify and re-do the experiment. Ask students why they think it is important to maximize the cost-efficiency when designing real-life applications. Discuss the importance of cost-efficiency for NASA missions. Discuss the MESSENGER mission to Mercury and why it needs a sunshade. If you had students participate in the Internet project, you can discuss their results here.

Assessment

You can use Page 3 of Student Worksheet 1 describing the students' design of the experiment and shade, Pages 2-7 of Student Worksheet 2 for assessment, as well as the Student Challenge Worksheet.