Lesson 7:
Building an Insulated Water Bottle

Overview

Students investigate the insulating properties of a variety of materials. Using their knowledge of heat transfers, students design an insulated water bottle.

Teacher Background

In the previous lesson students explored the conductivity of different materials and recognized that certain materials conduct heat better than others. In this lesson, students are asked to use their knowledge of conductivity to design a bottle that keeps water cold. This will require students to shift their focus to materials that do not transfer heat readily. These materials are known as insulators. One must use caution in thinking about conductors and insulators as definitive categories. Rather they fall along a continuum. Clearly some materials such as copper are on the conductor "end" of the continuum and materials like paper or wood are on the insulating "end" of the continuum. When selecting materials for a particular task or item, keep in mind that each material's limitation could prove to be another materials' strength- it all depends on the purpose. Thankfully, people wouldn't make mittens out of copper, an effective conductor. Wood, paper, cloth, and air are poor conductors of heat but are effective insulators. 1

Insulators have helped humans stay warm or cool for thousands of years. They have also been used to keep food warm and cool. Think of the mitten in the first lesson. People wear mittens when they want to slow down the transfer of body heat to the surrounding cooler environment. People use mittens as a kind of barrier between warm and cold air. Yet some mittens seem to be more effective than others at doing so. Why? Is it the thickness of the mittens, the material the mittens are made of or, could it be a combination of both? Perhaps the size of the mitten plays a part. Larger mittens enable the use of air space trapping molecules, whereas tighter fitting mittens do not. Which works better? Think about the old advice of wearing layers to keep warm. Layered clothing traps air between each layer thus cumulatively adding in the fabric's insulation effects and reducing the loss of body heat. As the mitten demonstrates, insulation is used to provide a barrier that minimizes the transfer of heat. Insulators can be used to keep items cold or hot. They do so by minimizing conduction, convection, and/or radiation.

What properties make “good insulators?” Density plays a role. The further apart atoms are from each other, the more difficult it is for a heat transfer to take place. Because of this gases such as air, which molecules are spread far apart, make better insulators in general than liquids. The molecules of liquids are further apart than solids making liquids in general better insulators than solids. By removing the atoms altogether (as in a vacuum), heat transfer by means of conduction and convection is eliminated, but radiation comes into play.

Heat transfer by radiation presents other considerations. Ever notice that many thermoses are made of reflective or shiny material? If a thermos is full of hot soup the shiny surface inside the thermos wall reflects the heat (infrared radiation) of the hot soup back to the hot soup keeping the soup hotter for longer periods of time. Why are people urged to wear white clothing in the summer as opposed to dark colors? White reflects heat and light better than dark colors and keeps the person cooler. Dark colors absorb light and heat more than light colors. Many items, such as home insulation, auto shades, space suits, hot/cold food bags, ice cream containers, etc. are also reflective and are used as insulators for that reason.

The focus of this lesson for students is, “How can knowledge of conductors and insulators be used to keep ourselves and different items warm or cool?

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Key Ideas

- Different materials conduct thermal energy at different rates. Metals conduct heat rapidly. Other materials, such as plastic and wood, do not conduct heat rapidly.
- Knowledge of thermal conductivity differences is used to develop products and technologies that allow people to safely and efficiently use heat.
- Depending on how they are used, materials can be used to slow or accelerate heat transfers.

Lesson Goals

Students will:
- recognize that a thermal conductor is a material that allows heat to readily transfer through it.
- recognize that heat is conducted at different rates through different materials.
- use their knowledge of heat transfers to design an insulated water bottle.

Vocabulary

(thermal) conductor: a material that conducts heat well and quickly; metal is a good thermal conductor.

(thermal) insulator: a material used to reduce the rate of heat transfer.

Preparation

- Determine whether students will be responsible for bringing in insulating materials or whether the teacher will gather the investigation materials.
- Collect empty sports drink plastic bottles or other uniformly sized/shaped bottles. Each student will need one bottle. Have a few extra bottles on hand – one will be used as a "control."
- Consider how often temperature in the insulator bottles will be taken – some prefer every 3 minutes; others take an initial temperature at the beginning of the class and another at the end of the class.

Safety

The first part of this investigation requires the use of hot tap water by students. Double check the temperature of the school's hot water to make certain students would not be accidentally burned if water contacts their skin.

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Materials

Item	Quantity
For student experiment: • 4-500 mL containers (beakers) of hot tap water (Alternatively, could use insulated take out coffee cups with covers- this eliminates the need to cover cups with plastic wrap.) • 4 thermometers • plastic wrap to cover containers and "contain" insulating material around bottles.	1 per group of 4 students
Stopwatches or access to timer that displays minutes: seconds	1 per class or 1 per student group
A variety of insulating materials: • Aluminum foil • Packing peanuts • Fiber fill • Shredded or crumpled newspaper • Sawdust • Sand • Plastic bags • Cloth (samples of cotton, wool)	Enough for class (Students could be asked to bring items from home.)
Gallon size resealable bag	1 per student pair
Large storage tube (38 quart or suitable size)	1 per class
Hot tap water in storage tub	1 per class
Thermos and/or insulated hot/cold food bag – now available in many grocery stores (prop)	1 per class
Chilled (refrigerated) water (enough for students to fill insulated bottles)	1-2 gallons per class
Scientist's Notebook	1 per student
Student Handout 7.1: Insulation Investigation Planning Guide Student Handout 7.2: Sample Data Tables and Sample Graphs Students Handout 7.3: Keeping It Cool: Building an Insulated Water Bottle	1 per student

Time Required: 3-6 sessions

Session 1: Discuss insulation and plan in groups

Session 2: Conduct investigation

Session 3: Graph and discuss

Session 4: Plan for new insulation challenges; peer review

Session 5: Carry out the insulation challenges

Session 6: Discuss results; The Mitten Problem Redux

Connection to *Maine Learning Results: Parameters for Essential Instruction (MLR), and National Science Education Standards (NSES), and Benchmarks for Science Literacy (BSL)*

- Describe how heat is transferred from one object to another by conduction, convection, and/or radiation. MLR D3(6-8) j
- Heat moves in predictable ways, flowing from warmer objects to cooler ones until both reach the same temperature. NSES B (5-8)
- Thermal energy is transferred through a material by the collisions of atoms within the material. Over time, the thermal energy tends to spread out through a material and from one material to another if they are in contact. Thermal energy can also be transferred by means of currents in air, water, or other fluids. In addition, some thermal energy in all materials is transformed into light energy and radiated into the environment by electromagnetic waves; that light energy can be transformed back into thermal energy when the electromagnetic waves strike another material. As a result, a material tends to cool down unless some other form of energy is converted to thermal energy in the material. BSL 4E/M3* (6-8)
- Design and safely conduct scientific investigations including experiments with controlled variables. MLR B1(6-8) b
- Explain why it is important to identify and control variables and replicate trials in experiments. MLR C1(6-8) b
- Design a solution or product. MLR B2 (6-8) b
- Communicate a proposed design using drawings and simple models. MLR B2 (6-8) c
- Evaluate a completed design or product. MLR B2(6-8) e
- Suggest improvements for their own and others' designs and try out proposed modifications. MLR B2(6-8) f

Teaching The Lesson

Engage

1 Engage in introductory discussion about insulators.

Open the lesson by noting that there are a number of situations in which the transfer of heat is problematic. People have developed a number of ways to influence and regulate heat transfers by putting their knowledge of how heat is transferred into action. They develop technologies that are effective in slowing the rate of transfer or speeding up the rate of transfer. Let's consider a few examples:

> **Note:** *Consider gathering a few of the items mentioned below as props for the discussion.*

- *When it's cold outside, what do you put on before going out?* (People might wear a sweater or jacket, mittens) *Why? Where is heat coming from and where is it going?* (Clothing insulates or slows down the transfer of heat from your body to the environment.)

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- *Do you think some clothing material helps keep a person's heat from transferring better than others?* (Students may suggest down, wool, fleece are insulating materials.)
- *What do you use to take a pan of brownies out of a hot oven?* (People protect their hands with an oven mitt or use a potholder.) *Why?* (The mitt prevents heat from being transferred from the hot pan to your hand.)
- Ask students to suggest other devices they may have used or are familiar with that decrease or increases the rate of heat transfers. As students make their suggestions, discuss how heat is being transferred in each of the situations. (Cookware, firefighter's clothing, wetsuits, machinery, etc.)
- *How do people influence the heat transfers that occur in their homes and other buildings? In other words, what features do buildings have that aid in temperature regulation?* (People have heating and cooling systems of various sorts; insulation, windows, etc.)

Explain that in this lesson students will be exploring insulators. Discuss with students what an insulator is, how it is different than a conductor, and ask students to give examples of insulators they are familiar with. Students can think of insulators as materials that slow the rate of heat transfer.

Note: *As students share what they know about insulating materials listen carefully to gauge whether students (still) believe that certain materials are inherently warm or cold. As this lesson proceeds, consider having students monitor the temperature of the insulating materials throughout the investigation (beginning, middle, end) to help students overcome this persistent idea.*

Alternately, divide students into groups of 4 and have them discuss what they think will make a good insulator and why. Assign each student the task of bringing in one of the items chosen for testing. Have groups plan what each student is bringing in so there are no repeat test materials within a group. Wood shavings, scarves, dirt, mud, dog hair, horse hair, wool, aluminum foil, toilet paper, and mittens are items students may choose to test. Discourage students from bringing in housing insulation. Eliciting the help of students in gathering materials piques students' curiosity.

Explore

2 Introduce the investigation.

Explain that they will be planning and carrying out an investigation that explores the effectiveness of different types of materials as insulators. Each student group of 4 will select 3 different materials to insulate containers filled with 500 mL of hot tap water to determine which material has the best insulating properties. One container will serve as the control.

Alternately, student groups can be (randomly) assigned insulation types to test as a way to make certain all insulation types are investigated.

A variety of insulating materials should be available to students. Label each type. As students begin planning their investigation, encourage students to examine the different materials before deciding which materials their group would like to compare and before students make their predications.

Distribute a copy of Student Handout 7.1: Insulation Investigation Planning Guide to each student. Allow students time to plan their investigation using the guide. Direct students to record their investigation plan in their scientists' notebooks. Assist students as needed. Note any common questions or difficulties that arise as students are planning and address appropriately in the discussion that follows.

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3 Review investigation plans.

Before students begin, discuss the following:

- *What variables are there in this investigation?* (insulation materials)
- *Which variables are you changing?* (Students should only change the different insulation materials- everything else should remain the same in order for this to be a fair test: the container size, the amount of water, starting temperatures, taking temperature readings – all should remain constant.)
- *How will you know if the material is having an effect- slowing down the transfer of energy?* (Students should recognize that a control container is needed; one container that has not been insulated should be monitored as well and will be used for comparison.)
- *How often should temperature readings be taken during the investigation?* (Recommend that students take readings every 1-2 minutes.)
- *How will you record your observations?* (tables, graphs, observations) Alternatively, guide students in creating data tables and graphs or provide students with the sample data table found on Student Handout 7.2: Sample Data Table and Sample Graphs.

> **Note:** *Make certain that students have made a prediction prior to beginning their investigation. Give students a few minutes to make necessary edits to their plans.*

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4 Conduct the investigation.

Instruct students as to how to obtain the necessary investigation materials including how to safely access and measure hot tap water. Demonstrate for students how to unwrap or nest the insulating materials around the outside of the container. As students conduct their investigation, circulate among students, monitor student progress and ask questions that focus on student understanding.

Reflect And Discuss

5 Review, analyze, and discuss data.

Ask students to create a graph of their findings and write a conclusion supported with evidence in their scientists' notebooks. Gather students together for a scientists' meeting. Discuss the following:

- *What conclusions did you make?*
- *Were there differences in data?*
- *Were there differences in the way different groups conducted their investigation?*
- *Based on the data, which insulation slowed the transfer of heat the most? Which insulation slowed the transfer of heat the least?*

- *What is the source of heat in the investigation?* (Discuss the idea that the insulator is not a heat source. Be sure students recognize that insulators slow heat transfers. Ask students what temperature the insulating material is and/or monitor the temperature of the insulating materials as well to help students overcome the idea that some materials are inherently "hot" or "cold.")
- *If you could do the investigation again, what materials would you try?*
- *What new questions do you have about insulators and heat transfers*

6 Present new insulation challenge

Show students a thermos and/or an insulated (hot/cold food) bag that are available at many grocery stores. Ask students what they think these items would be used for. Students may not have thought about the possibility of using them to keep food like iced tea or frozen food cold on one day and then the next day use them to keep something like soup or pizza hot. *How is this possible?* Pass around the items and allow students to closely examine the materials from which these are made. While the items are being passed around the class, ask students to write about how they think these items can be used to keep things both cold and hot in their scientists' notebooks.

Once the items have been examined, ask if students think the insulating materials they investigated earlier could also be used to keep something cold.

Give each student a copy of Student Handout 7.3: Keeping it Cool: Building an Insulated Water Bottle and review the criteria. Make sure the students know ahead of time that their insulated water bottles will be placed in water – that might affect the choice of insulating materials. Explain that students will be working in pairs to plan, construct, and test an insulated water bottle. Ask student to bring their materials to school and consider giving students a 20 minute time limit to construct their bottles.

7 Construct insulated bottles.

Give students 20 minutes to construct their insulated water bottles following their plans. Students should wrap each bottle in plastic wrap to keep chosen insulation snug. Then put the bottle in plastic bag.

8 Examine peer's designs.

Ask students to place their insulated water bottle on their desks or in a designated area. Give each student pair a pad of sticky notes. Allow students a few minutes to examine the bottles created by their peers. As they examine the designs of their peers, ask students to write down a constructive comment, a suggestion, or question about the design and stick it on the desk next to the bottle. After students have had a chance to examine the different designs, share some of the comments that have been written on the notes with the class. Be sensitive to students' feelings when sharing comments and consider paraphrasing, posing comment as a question, or eliminating comments if they are inappropriate.

> **Note:** *Take time to discuss the purpose of share ideas and the need to maintain respect for each other while writing and reading comments.*

9 Test insulated water bottles.

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Fill a container, large enough for all insulated bottles to fit inside, with hot tap water. The hot water tub will simulate a hot day. Have each pair fill their water bottle with a uniform amount of refrigerated (chilled) water. Fill an extra bottle with the same amount of refrigerated temperature water to serve as the control. Have students take and record the starting temperature of the refrigerated water. Have students test their insulated bottles by placing their bottles in the hot water tub.

After 3 minutes have students check and record the temperature and again every 3 minutes. Alternatively, have students take an initial temperature at the start of class and then take the temperature at the end of class. Have students calculate the total temperature change in their scientists' notebooks.

Prepare and post a class data chart on the board, on an overhead, or a computer data collection program. Have students add their data to the class data chart.

10 Review findings and reflect on designs.

Review class data and discuss findings with students as before. Consider asking students to reflect upon some or all the following prompts before meeting.

- *What conclusions did you make?*
- *Describe how your bottle work compared with others in your class.*
- *Based on the class data, which types of insulated bottle designs slowed the transfer of heat the most?*
- *Why did you design the bottle the way you did? Use your knowledge of heat transfers to explain.*
- I*f you could redesign your bottle, what changes would you make and why?*
- *What new questions do you have about insulators and heat transfers?*

11 Revisit *The Mitten Problem* Redux.

Provide each student with Student Handout 7.4, *The Mitten Problem* Redux. Ask students to complete the task. Collect and review students' ideas. 11

Extensions

Student may:

- investigate early refrigeration methods ("ice box"). Ice houses and root cellars were commonplace in earlier times.
- View how ice was harvested from Maine lakes by the Sebago Ice Company. This 5 minute narrated clip, *Ice Harvest*, has uneven but discernable audio. Ice Harvest Sampler, 1930s-1940s, footage provided by Northeast Historic Film, www.oldfilm.org To view movie clip go to: http://windowsonmaine.library.umaine.edu/fullrecord.aspx?objectId=6-2400 click on "Moving Image"
- view *How Do You Keep Lemonade Cool?*, a video clip adapted from *FETCH!*™ which shows two cast members teaming up to take on a design challenge: Make a lemonade stand that keeps lemonade cool and is sturdy and transportable. Teachers may like to show this to students in conjunction with their insulated bottle challenge. http://www.teachersdomain.org/asset/eng06_vid_lemonade stand/
- read *A Chilling Story: How Things Cool Down* (1991) by Eve and Albert Stwertka. This book describes cooling by heat transfer, cooling by evaporation, and cooling by expansion. It also has chapters describing how refrigeration and air conditioning works.

Connection to Maine Agencies

A Maine Energy Education Program (MEEP) is a no cost resource for schools and teachers in Maine. MEEP representatives and will come to interested schools, free of charge, to guide and support the concepts in lesson and have programs that supplement concepts in this lesson:

- **School Energy Efficiency Investigation:** Students use tools to see how their school uses energy and where energy is wasted. Tools include an infrared thermometer, a temperature/humidity datalogger, a light meter and a Kill A Watt meter. Students can then make recommendations on how energy can be conserved in their school. This project can be combined with the Greenhouse Gas Surveys being offered by Maine DEP.

More information can be found on the MEEP website: www.meepnews.org/classroomactivities.

For schools in Aroostook County, a Maine Public Service (MPS) representative will come to interested schools, free of charge, to guide and support concepts developed in this lesson. A description of programs is available at www.mainepublicservice.com. Click on the education section of the site. To schedule a presentation contact Nancy Chandler at 207.760.2556 or nchandler@maine publicservice.com.

Online References and Resources

Lesson adapted from **Utah Education Network** in partnership with the Utah State Office of Education and the **Utah System of Higher Education**, Insulation ExperimentationLesson. http://www.uen.org/Lessonplan/preview.cgi?LPid=21569

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Houck, C. (2000-5). *Insulators, Conductors, and Energy Transfer*. Beacon Learning Center, U.S. DOE Technology Innovation Challenge Grant.

How Stuff Works: How Thermoses (Vacuum Flasks) Work: http://www.howstuffworks.com/thermos.htm

Explanation of Insulation R-values: http://www.school-for-champions.com/science/thermal_insulation.htm

Article: Gas Filled Cold Weather Clothing Wins Awards BYU student's clothing invention: http://inventorspot.com/articles/gas_filled_clothing_wins_awards_13558

Article: Surviving Olympic Heat
ClimaCool clothing
http://www.sciencenewsforkids.org/articles/20040630/Feature1.asp