Building Materials to Study Heat Transfer

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Grade: Middle and high school

Lesson Duration: 120 minutes

Background Information for Teachers and Students

Building materials are the materials used in construction. Building materials include sand, clay, rocks, wood and twigs and leaves, stone, bronze, iron, plastic, silicon, biomaterials, and nanomaterials. The study of building materials provides the makeup of habitats, influences the quality of human life, and has an impact on the environment. The materials used may identify a particular era, reflect popular design and style, and illustrate culture and traditions.

Building materials are models for students to explore the driving question: How does heat move? Students hold a number of misconceptions about heat transfer: 1) Temperature is a property of a particular material or object, and 2) Objects are sources of heat. Students may think that a metal is naturally cool and a plastic would be warmer. Students may think their own sweater, gloves, and blankets are sources of heat. The lesson plan will be an investigation to help students develop an accurate scientific understanding of heat transfer.

Lesson Objective

Students will investigate heat transfer. Defining the related vocabulary of insulator, conductor, heat, energy and temperature makes the lesson topic accessible to more students and bridges elementary and advanced concepts of heat and insulation. Students should be instructed, if they do not have prior knowledge, on how to measure temperature using a thermometer or temperature probe and be able to collect data using a meter stick, timer, and calculator.

The activities described below in the **Instructional Process** sections are designed to illustrate differentiated instruction and consider different levels of prior knowledge on heat transfer. The curricular and instructional considerations are three-fold. Have students experiment to describe the ways heat was produced and recognize that heat moves from warmer objects to cooler ones. Explain the idea that energy is an important property of objects, and illustrate energy transfer in the form of heat and that heat results from the motion of molecules. A third consideration is to compare and contrast actions that give off heat and materials that may prevent some heat from dissipating into the environment.

Each activity is organized in the 5E instructional model to help students build their own understanding from the experiments and discussion of new ideas. The 5Es represent five objectives for teaching and learning: Engage, Explore, Explain, Extend or Elaborate, and Evaluate. Each activity includes probing questions to support student engagement, comprehension, and application of the content. All students should be able to explain what is heat and how it is transferred, and understand that not all materials have the same insulation abilities. More advanced students will determine and compare the insulating properties of several materials and discover that some glass panes let thermal energy pass through more readily than others.

Instructional Process

Activity 1: Driving Question – How does heat move?

Materials needed:

- Chocolate bar
- Lamp
- 250 ml beakers (plastic) – labeled 1, 2, and 3
- Thermos of hot water
- Insulated container of ice water
- Red or orange food coloring
- Plastic transfer pipettes
- Laminated images illustrating an example of conduction, convection, and radiation
- Data sheet

Safety (precautions to avoid possible injury):

Students should be instructed to:
- not touch the hot lamp.
- not operate the infrared camera.
- avoid spilling the water.
- use a pipette to transfer food coloring.

Engagement:

Hold a chocolate candy bar in your hand.

Probes:

What am I holding?

What happens if you hold the candy bar in your hand too long before you eat it?

Why does this happen?

Turn on the lamp and let the light bulb glow. Ask for a student volunteer. Ask the volunteer to place his/her hand near the bulb. Safety: Remind students that they are not to touch the bulb.

Probes:

Can you feel the heat?

Is heat being transferred from the bulb to the hand?

What is the difference between the way the heat is transferred between the chocolate bar and the bulb?

Exploration:

Organize the class in small groups. Each group is given 3 beakers (labeled 1, 2, and 3), 1 food coloring bottle, and 1 transfer pipet. Each student will be given a data sheet. Remind the students not to use the materials until all instructions are given. "Think aloud" the instructions for this activity using room temperature water while students watch. The think aloud will allow the teacher to verbalize the steps of the procedure to clarify for students the instructions and model the appropriate use of materials. Fill beaker 1 for each group with room temperature water. Students do the experiment with beaker 1 as you repeat the steps the second time.

Probes:

Why is a pipet used to put the food coloring in?

What is the food coloring showing us?

Fill beaker 2 with ice water and beaker 3 with hot water and the student groups repeat the experiment procedure on their own.

Students will use Table 1A to record their results.
Table 1A.

Beaker number	Temperature of water	Observations

Probes:

Is the food coloring moving?

Is it moving at different speeds?

Which one moved fastest?

Which one moved slowest?

What is different about the water in the beakers?

Do we have enough information to tell which temperature had the fastest motion?

Post the data collected by the students on the table. Display the compiled results for the class with a smart board or document camera.

Speed of food coloring	Group 1	Group 2	Group 3
Fastest			
Medium			
Slowest			

Probe:
How can this experiment explain the transfer of heat?
Explanation:
Probes:
Is there more than one method of heat transfer?
If so, then how are they similar and different than one another?

In the explanation, define the following vocabulary. Prompt students to think about the three activity examples (chocolate bar, light bulb, and food coloring and water).
Conduction – The transfer of heat through a material by direct contact.
Convection – The transfer of heat in a fluid (gas or liquid) as a result of the movement of the fluid itself.
Radiation – The transfer of heat via electromagnetic waves through space.

Distribute a Zip lock bag with laminated pictures and a data sheet (Table 1B). The data sheet has two parts. First, students are to look at pictures placed in the Zip lock bag and identify each picture as representing conduction, convection, or radiation. The teacher will have to create a table with the appropriate number of rows. On the second part of the data sheet, ask the students to draw an image showing heat transfer and indicate with arrows the direction the heat is being transferred.

Table 1B.

Photo	Conduction	Convection	Radiation
1			
2			
3			
4			
5			
6			

Conduction	Convection	Radiation

Ask student volunteers to display their examples on a document camera. Have the class to conclude if the examples are correctly identified as conduction, convection, or radiation.

Elaboration:

Display an infrared image. Infrared images can be viewed online via Google Earth.

Probes:

Has anyone ever seen any image like this?

Introduce the topic of thermal radiation.

What is this image called?

Explain that all objects give out energy as thermal radiation. This energy travels as infrared (IR) rays. We cannot see IR rays. We can feel IR rays from a hot object as it raises the temperature of the skin.

What do you see?

A device called an infrared or IR camera allows us to show that all objects give out IR rays. An IR image displays warmer and cooler areas of an object. Hotter objects give out more IR rays and appear brighter on the image than cooler ones.

Evaluation:

Ask the students if cold can be transferred, and to explain their response.

Extension:

Introduce students to Energy2D, a simulations program that models conduction, convection, and radiation. Students will use the program controls to explore variables such as different heat and mass flows in two-dimensional structures. Environmental conditions such as sunlight and wind can be adjusted.

Activity 2: Driving Question – Does Heat Flow Change through Different Types of Materials?

Materials needed:

- Cups of various composition: foam, paper, glass, plastic, metal or other material selected by the teacher For *Science Saturday*, materials in research development by the building materials science group should be included.
- Lid (construct or purchase) with access for a thermometer
- Water of a given temperature
- 100 mL graduated cylinder (plastic)
- Thermometer or Temperature Probe – one for each cup
- Timer
- Data sheet

Safety (precautions to avoid possible injury):
Students should be instructed to:

- avoid spilling the water.
- avoid dropping or rough handling of the thermometer or temperature probe.
- use a thermometer or probe to measure the temperature of the water. A temperature exceeding 70°C is not recommended.

Engagement:

Show the students samples of different building materials. For *Science Saturday*, materials in research development by the building materials science group should be included. Ask the students to describe each sample as an insulator or conductor.

Probes:
What is an insulator?
What characteristics would insulators have in common?
What is a conductor?
What characteristics would conductors have in common?

Exploration:
Prior to the start of the activity, the teacher will construct or purchase a lid for each cup, and prepare enough water to place 100 mL into each cup for each group. All lids will be need to be the same. Organize the class in small teams. Each team is given a data sheet to record their results.

Have the students take and record the room temperature. For each cup, the team will measure 100 mL of water and put it into the cup, place the lid and thermometer in the opening of the lid. Ask the students to check that the thermometer or probe is in the water. Each group will measure the beginning temperature of the cup, and leave the thermometer or probe in the water as temperature readings are made. Students will take the temperature of the cup at 3-minute intervals for a total of 30 minutes. The temperature measurements will be recorded using the same procedure until all cups have been tested.

Record the results in the data table.

Table 2.

Room temperature: _________					
	Cup #1	Cup #2	Cup #3	Cup #4	Cup #5
Type of material in cup					
Initial water temperature					
3 Min:					
6 Min:					
9 Min:					
12 Min:					
15 Min:					
18 Min:					
21 Min:					
24 Min:					
27 Min:					
30 Min:					

Explanation:

Have the students to use the data to explain the results.

Probe:
Why do you think this happened?
Compare and contrast the materials of the cups. How does this experiment relate to the materials of the cups?
Define the vocabulary terms – insulator and conductor.

Insulator – material that does not allow a transfer of heat.

Conductor – material or object that allows energy in the form of heat to be transferred.

Have the students to use the data collected in the experiment to answer the following questions:
Name two materials that are good thermal insulators.
Name two materials that are good insulators.

Evaluation:

Which would be a better choice for building houses that need less internal heating – red brick or concrete? Explain.

Why is stainless steel good for making cooking pots? Explain.

Activity 3: Driving Question – Does heat loss vary with different types of windows?

Materials needed:
- Glass window panes (clear glass, single pane; UV coated glass, single pane; double pane clear or UV coated)
- Thermometers or temperature probes
- Light meter
- Clip light with 75 watt incandescent bulb
- Meter stick or ruler
- Clay

Safety (precautions to avoid possible injury):
Students should be instructed to:
- not touch the hot light bulb.
- avoid dropping the clip light.
- avoid directing the light into the audience.
- avoid dropping or rough handling of the thermometer or temperature probe.

Engagement:

Show the students samples of different glass panes.

Probe:
If you were a consumer (shopper), would you choose to buy one of the glass panes for your bedroom window? Explain your answer.

Exploration:
To run the experiment, the teacher will need to collect glass pane samples. Use clay to construct a stand to support a pane of glass so that the glass will stand on edge.

Probe:
Why do you think clay is used to construct the stand for this experiment?

Place the class in two – four teams. Each team will work with a pane of glass – the same type of glass or a different type of glass from another team. Each team will begin the experiment by measuring light intensity.

Using the meter stick or ruler, have the teams place a clip light at the 25 cm mark in front of the pane of glass and turn on the light. The students will allow the light to shine for 5 minutes. The light intensity will be measured with the light meter. Place the meter at the 25 cm mark in front of the pane of glass. The light will be turned off and another light intensity reading taken. After measuring light intensity, the teams will place the clip light at the 25 cm mark in front of the pane of glass. The thermometer or temperature probe will be placed 2 cm in front of and behind the pane of glass. Record the temperature in front of the glass pane, which is the side the light source directly faces. Then record the temperature behind the glass pane. All steps will be repeated for each additional type of glass pane to be tested.

Table 3.

Glass pane	Temperature in front of pane of glass	Temperature behind the pane of glass
Clear glass, single pane		
UV coated glass, single pane		
Double pane clear		
Double pane UV coated		

Explanation:

Each group will record their data in the table. Allow each team to bring their results back and describe and compare temperature differences in front of and behind the pane of glass.

Probes:
Were the temperature ranges the same or different with the panes of glass?
What four terms can be used to describe the glass panes that prevent heat loss?

Evaluation:

Probe:
If you were a consumer (shopper), which one of the glass panes would you purchase for your bedroom window? Explain your answer.

Extension:

Student teams will conduct computer searches to determine the energy performance ratings for two windows. Each team will post the properties of the windows evaluated by the team on the classroom board. The class will use the collected data to compare and contrast the windows to select window properties most appropriate for local climate. Next, each team will conduct computer searches to select two roof surface properties for homes and buildings that would reduce the "Urban Heat Island Effect." The teams will post their data on the classroom board, and the class will review roof surface properties.

Each team will create a building model with the windows and roof materials researched by the class. The properties of the material samples are posted on the classroom boards for student reference. The team will draw a simple building model, and label and describe the material properties they selected. The team may build the model or create a model using software such as DesignBuilder. For the final presentation, each team will write a paragraph discussing the estimated effects on energy use by the building created.

Materials needed:
- Laptops (Provide as many laptops as possible. Divide the students into groups.)
- DesignBuilder software (A 1-month free version can be downloaded from designbuildersoftware.com)

Activity 4: Driving Question – Do compact fluorescent light bulbs or incandescent light bulbs generate the most heat?

Materials needed:

- Compact fluorescent light bulb
- Incandescent light bulb
- Light socket outlets
- Meter stick
- Thermometers (remote wire thermometers or thermometers used for cooking are recommended)
- Graph paper

Engagement:

Show the class both light bulbs. Ask the following question: Which light bulb do you use at your home? Then ask the students to form a hypothesis: Which light bulb will generate the most heat?

Exploration:

Organize the class in two groups. Each group will view either one compact fluorescent light bulb or one incandescent light bulb. Make sure the light bulbs are at different stations with 2 feet or more between the stations. Using the meter stick or ruler, place a thermometer at the 4-5 cm mark in front of each light bulb. Students will measure and record the temperature around each light bulb at one-minute intervals for 10 minutes. Take the first measurement with the power off. A student in each group will then turn on the light bulb. Measure and record the temperature after 1 minute and repeat recording the temperature for each minute.

Table 4.

Time (minutes)	Compact fluorescent light bulb (Fahrenheit)	Incandescent light bulb (Fahrenheit)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		

Optional: Students will plot the table data on graph paper for each light bulb. The x-axis represents time and y-axis is temperature data.

Explanation:

Ask students to review the collected data for patterns in the heat output for each light bulb. Which light bulb generated the most heat?

Elaborate:

Based on the Explore data, ask students to hypothesize which light bulb (compact fluorescent light or incandescent light bulb) releases more energy. Students will calculate the electrical energy (kilowatt-hours) used by each light bulb in one hour using the power rating for each light bulb. The power rating is printed on the top of the light bulb. Instruct students to multiply the light bulb's power rating (Watts) by 0.001.

Students will determine which light bulb would consume more energy if left on for 8 hours. The equation the students will use to calculate the amount of energy used by the light bulb is the number of kilowatt-hours (from the first elaborate calculation) multiplied by the number of hours. After students complete the energy consumption for each light bulb, the teacher will explain to students that incandescent light bulbs release approximately 90% of their energy in the form of heat.

Safety:
Do not touch the light bulbs. Do not drop the thermometer.

Key Vocabulary

- Conductor
- Energy
- Heat
- Infrared rays
- Insulator
- Temperature
- Thermal Radiation
- Thermometer

Safety and Cleanup Required

Because infrared devices are used in Activity 1 of this lesson, care must be taken to insure safety. Students must be adequately supervised, and should not be allowed to handle the camera without direct adult engagement. Safety rules (do not spill water and food coloring, how to carefully handle a thermometer and temperature probe, and meter sticks and rulers) should be explicitly addressed before the experiments are performed. After the investigations are complete, students should return all materials.

Handle glass samples carefully

Do not drop the instruments

Alignment with Tennessee Science Standards
Embedded Inquiry
GLE 0507.Inq.1 Explore different scientific phenomena by asking questions, making logical predictions, planning investigations, and recording data.
GLE 0507.Inq.2 Select and use appropriate tools and simple equipment to conduct an investigation.
GLE 0507.Inq.3 Organize data into appropriate tables, graphs, drawings, or diagrams.
GLE 0507.Inq.4 Identify and interpret simple patterns of evidence to communicate the findings of multiple investigations.
GLE 0507.Inq.5 Recognize that people may interpret the same results in different ways.
GLE 0507.Inq.6 Compare the results of an investigation with what scientists already accept about this question.
GLE 0507.10.2 Conduct experiments on the transfer of heat energy through conduction, convection, and radiation.

Physical World Concepts: Standard 2 - Thermodynamics
CLE 3237.2.1 Explore the relationships among temperature, heat, and internal energy.

Environmental Science: Embedded Technology & Engineering
CLE 3260.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
CLE 3260.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.

Chemistry I: Embedded Technology & Engineering
CLE 3221.T/E.2 Differentiate among elements of the engineering design cycle: design constraints, model building, testing, evaluating, modifying, and retesting.
CLE 3221.T/E.3 Explain the relationship between the properties of a material and the use of the material in the application of a technology.

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