Exploring Heat Transfer by Conduction

Grade Band: Middle School - High School	**Topic:** Heat Transfer by Conductivity

Brief Lesson Description:
Students explore how heat transfer depends on both material thermal conductivity and the quality of surface contact between components. Students apply their learning to develop a solution to a real-world problem.

Performance Expectation(s):
MS-PS3-3: Apply scientific principles to design, construct, and test a device that either minimizes or maximizes thermal energy transfer.

HS-PS3-4: Plan and investigate to provide evidence that the transfer of thermal energy when two components of different temperatures are combined with a closed system results in a more uniform energy distribution among the components in the system (Second Law of Thermodynamics).

Specific Learning Outcomes:

Students will be able to:
1. investigate and compare contact quality between metal plates using pressure-indicating film and different interface materials
2. analyze how thermal conductivity and surface contact area affect heat transfer using experimental data and known material properties to support their reasoning.
3. apply scientific principles of heat transfer to recommend and justify an effective thermal interface design for a real-world application, such as cooling a computer chip.

Narrative / Background Information

In modern electronics—from smartphones to gaming computers—managing heat is a critical engineering challenge. As electronics operate, they generate heat, which, if not efficiently transferred away, can lead to performance issues or hardware failure. Heat sinks are engineered to pull thermal energy away from these components and transfer it into the surrounding air. However, the efficiency of a heat sink doesn't rely solely on its material; it also depends heavily on how well it makes contact with the component it's cooling. Tiny air gaps or surface imperfections between the materials can significantly reduce heat flow, even when using highly conductive materials like copper.

Teachers do not need advanced engineering knowledge to lead this lesson, but they should be familiar with basic heat transfer concepts—especially conduction—and how material properties like thermal conductivity influence energy flow. It's also helpful to review how pressure film works and how to read the color results to estimate contact area.

This lesson expects students to have a basic understanding of heat transfer, including the concept that heat moves from areas of higher temperature to those of lower temperature. Additionally, students should understand the concept that materials have unique properties that impact how they conduct energy (including heat). Finally, students should have basic scientific inquiry skills, including using data to draw conclusions.

Science & Engineering Practices:	**Disciplinary Core Ideas:**	**Crosscutting Concepts:**
Constructing Explanations and Designing Solutions Apply scientific ideas or principles to design, construct, and test a design of an object, tool, process or system. (MS-PS3-3) **Planning and Carrying Out Investigations** Plan and conduct an investigation individually and collaboratively to produce data to serve as the basis for evidence, and in the design: decide on types, how much, and accuracy of data needed to produce reliable measurements and consider limitations on the precision of the data (e.g., number of trials, cost, risk, time), and refine the design accordingly. (HS-PS3-4)	**PS3.A Defintions of Energy** Temperature is a measure of the average kinetic energy of particles of matter. The relationship between the temperature and the total energy of a system depends on the types, states, and amounts of matter present. (MS-PS3-3) **PS3.B Conservation of Energy and Energy Transfer** Energy is spontaneously transferred out of hotter regions or objects and into colder ones. (MS-PS3-3) Energy cannot be created or destroyed, but it can be transported from one place to another and transferred between systems. (HS-PS3-4)	**Energy and Matter** The transfer of energy can be tracked as energy flow through a designed or natural system. (MS-PS3-3) **Systems and Systems Models** When investigating or describing a system, the boundaries and initial conditions of the system need to be defined and their inputs and outputs analyzed and described using models. (HS-PS3-4)

	Uncontrolled systems always evolve toward more stable states-that is toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down). (HS-PS3-4) **PS3.D Energy in Chemical Processes and Everyday Life** Although energy cannot be destroyed, it can be converted to less useful forms-for example, to thermal energy in the surrounding environment. (HS-PS3-4) **ETS1.A: Defining and Delimiting an Engineering Problem** The more precisely a design task's criteria and constraints can be defined, the more likely it is that the designed solution will be successful. Specification of constraints includes consideration of scientific principles and other relevant knowledge that is likely to limit possible solutions. (MS-PS3-3) **ETS1.B: Developing Possible Solutions** A solution needs to be tested, and then modified on the basis of the test results in order to improve it. There are systematic processes for evaluating solutions with respect to how well they meet criteria and constraints of a problem. (MS-PS3-3)	

Possible Preconceptions/Misconceptions:
Students may mistakenly believe that using a highly conductive material alone guarantees effective heat transfer, without realizing that poor contact can significantly reduce performance. They might also assume that air or sponge layers help because they "fill gaps," not recognizing that these materials are thermal insulators. Additionally, some students may confuse thermal energy flow with temperature, thinking hotter objects "store" more heat instead of transferring it.

LESSON PLAN – 5-E Model

ENGAGE: Opening Activity – Access Prior Learning / Stimulate Interest / Generate Questions:

Start the lesson by showing the video "Heat-Sinks-Why Bother? See why with thermal imaging" where they will observe a video of a thermal camera monitoring a gaming computer with and without a heat sink.

After watching the video, have students use the "think-pair-share" strategy for students to consider the following prompts:
Why does the computer get hot?
What do heat sinks do, and why are they often made of copper or aluminum?
Have you ever touched a metal object that felt hot or cold? Why?

After discussion, explain today's objective to the students:
"Today we're going to explore how both **contact area** and **material properties** affect how well a heat sink can transfer heat."

EXPLORE: Lesson Description – Materials Needed / Probing or Clarifying Questions:

Activity: Heat Sink Lab
In this hands-on lab, students investigate how both contact quality and material thermal conductivity affect heat transfer between metal plates—key principles in designing heat sinks for electronics. Using pressure-indicating film, they compare three setups: dry contact, a thin sponge layer, and a copper foil with thermal paste. By observing pressure distribution and researching the thermal properties of each material, students learn that effective heat transfer requires both good surface contact and a highly conductive interface. This real-world engineering challenge helps students apply physical science concepts to modern technology solutions.

Teacher Setup Instructions:
Before the lab, prepare kits for each group containing two 2"x 2" or 3”x 3” metal plates (such as these steel plates), four screws (1.5" length), eight matching washers, four hex nuts, a small piece of thin sponge, a sheet of 2–4 mil copper foil, a dab of thermal paste (enough for one trial), and three strips of pressure-indicating film (such as Fujifilm Prescale). Pre-cut the pressure film and sponge to match the plate size. Ensure each group has access to a torque wrench capable of 15 in-lb (1.7 N·m), and model how to use it evenly across bolts in a crisscross pattern. To prevent paste from contaminating the film, remind students to handle materials with clean hands and to clean up between trials.

Teacher Activity Instructions:
Divide students into small groups and provide each student with a copy of the student lab handout. During the activity, circulate to ensure students are assembling their plates correctly, using even pressure and proper torque. Watch for groups overtightening or failing to align materials, as this can skew the pressure paper results. Ask probing questions like, “What does this pressure pattern suggest about the contact area?” or “How might the sponge or paste affect heat flow?” Encourage students to compare their group’s results and discuss which setup would best cool a computer chip based on both contact area and thermal conductivity. Reiterate that good design depends not just on materials, but also on how well they are used.

EXPLAIN:

Summarize the students’ findings from the lab. Reiterate that both the conductivity of the materials used and increasing contact between surfaces results in improved heat transfer.

Introduce students to Carbice, a company that has created an innovative solution for heat transfer that works on maximizing both of these needs. Show the video “How Carbice Works”. Then discuss the following prompts as a class:

“How does Carbice’s material solve both contact and conductivity issues?”
“Why is a nano-scale solution effective?”
“What did the pressure paper show us about the importance of surface conformity?”

Follow the discussion up with a mini-lecture that covers the following points:
1. Define **thermal conductivity** and **thermal contact resistance**
2. Heat flows more easily through materials with high conductivity **and** good contact area
3. Materials like thermal paste reduce gaps (air = bad conductor)

ELABORATE: Applications and Extensions:

Ask students to consider the question ***“How might this new technology improve our world?”*** Then show the video “The Carbice Story” that explains how this tech was developed and how it is being used.

Explain to students that it is now their turn to design a solution to a real-world problem like Carbice does by completing a design challenge. "Imagine you are designing a heat sink interface for a high-powered gaming computer chip."

In their lab groups, have students create a poster that includes the following:

- Choose the best interface combo (dry, sponge, or copper foil/paste)
- Justify using both **measured contact area** and **thermal conductivity** of materials
- Draw a cross-section diagram showing heat flow and material layers
- Label contact resistance points and high conductivity paths

EVALUATE:

Formative Monitoring (Questioning / Discussion):
Discussion prompts are found in ***bold, italics*** and can be used to check student understanding throughout the lesson. Additionally, you can use the students' lab handouts to assess understanding.

Summative Assessment (Quiz / Project / Report):
Using the design from the elaborate section, you can use any of the following to assess student understanding:
- **Written Explanation:** Which material interface would you recommend and why?
- **Diagram Analysis:** Use their drawing to assess understanding of the material role in heat transfer.
- **Claim-Evidence-Reasoning:**
    - *Claim:* The copper foil and thermal paste assembly provides the best cooling.
    - *Evidence:* It has the highest contact area and copper has high thermal conductivity.
    - *Reasoning:* Greater surface contact allows more heat transfer, and copper conducts heat quickly.

Elaborate Further / Reflect: Enrichment:
Option 1: Research new materials being used in space, electric vehicles, and smartphones for heat transfer, such as graphene, carbon nanotubes, or liquid metal cooling systems.
Option 2: Design a prototype interface using 3D modeling software such as Tinkercad or OnShape.
Option 3: Explore carbon-based materials like graphene or carbon nanotubes and how they are being used to innovate technologies in fields such as aerospace, medicine, and electronics.

CAREER CONNECTIONS

There is a wide variety of careers students can pursue in the Materials Science industry. From studying the properties of materials as a materials scientist to designing cutting-edge technologies as a material engineer, there are many interesting professions for students to explore. The following activity will provide students with an opportunity to learn about these careers.

Go to https://usasciencefestival.org/resources/ to access the Student Career Resources.

Select the Materials Science tile

Have students browse the careers within your chosen cluster. Select one career that they would like to learn more about. They should then gather the following information using the student graphic organizer or in a class notebook:

- Job description and typical responsibilities
- Education and training required
- Skills and qualities needed
- Average salary
- Work environment and schedule
- Professional Organizations, Educational Programs, and Internship & ApprenticeOpportunities

Choose a Choice Board Activity and use the information gathered to complete the chosen activity.

Career Interview	**Pros and Cons Chart**	**Career Poster**
Write a set of 5-7 questions you would ask someone in this career. Include the responses based on your research.	Make a T-chart listing at least five pros and five cons of the career based on your findings.	Design a poster or infographic showcasing key details about the career (e.g., job tasks, salary, skills, and job outlook).

Provide students with an opportunity to share their findings with peers or with you.

SOCIAL EMOTIONAL LEARNING ACTIVITY

CASEL Competency Addressed: Self-Awareness
Scientists and Engineers at Carbice have used content knowledge and creative thinking to design the Carbice pad to overcome engineering challenges with heat transfer. Explain to students that this type of innovation requires practice! Today they will participate in an activity to help them start thinking creatively about how to use common materials in different ways.

Objective: Practice flexible thinking by challenging assumptions and exploring alternate realities.
Materials: "What if" scenarios (Printed and cut apart or digitally on screen)

Instructions:

1. Present an open-ended "What if" scenario to students (this may be done digitally or on paper.)
2. In small groups or pairs, brainstorm for 5 minutes: What problems would that cause? What creative solutions could people invent?
3. Share the most interesting or hilarious ideas with the class.
4. Discuss the following questions as class:
   What did you notice about how your thinking changed as the prompts got more unusual?
   (Encourages students to reflect on their ability to adapt and think beyond initial ideas.)
   Was it hard to come up with creative solutions at first? What helped you think in new ways?
   (Promotes awareness of strategies that support flexible thinking, like collaboration or imagination.)
   How could practicing this kind of thinking help you in real life, especially in science or engineering?
   (Connects the creative thinking skill to real-world problem-solving and innovation.)

Materials Required for This Lesson/Activity	
Quantity	**Description**
2 per Group	Metal Plates(2”x2” or3”x3”) with 4 holes (Example Plates)
4 per Group	Screws (1.5 inch Long)
8 per Group	Matching Washers
4 per Group	Hex Nuts
1 per group	Thin Sponge (cut to same size as metal plates)
1 per group	2-4 mil Copper Foil (cut to the same size as the metal plates)
3 per group	Pressure paper (cute to the same size as the metal plates) (Suggested Paper)
1 per group	Dab of Thermal Paste (Example Paste)

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