Telelab Unit: Thermal Conduction

Prerequisites

Before continuing with this unit, students should already be able to:

- Define temperature as the macroscopic manifestation of average kinetic energy of molecules
- Explain the conservation of energy: energy cannot be created or destroyed; it can only be converted from one form to another

Learning Goals

After completing this unit, students will be able to:

- **[NGSS MS-PS3-4]** Plan an investigation to determine the relationships among the energy transferred, the type of matter, and the change in the average kinetic energy of the particles as measured by the temperature of the sample.

Duration

1 class period, 90 minutes each

Materials

Ingredients & amount	*Measuring equipment*	*IR kit*
• Wooden ruler, 1 • Metallic ruler, 1	N/A	• IR camera • Android phone • Power bank • Tabletop phone mount

Pre-Class Preparation

- Fully charge the Android phone and the power bank.

What do you already know about thermal conduction?

Motivation

Ask students to define or explain thermal conduction based on what they currently know. If students struggle, ask them to list or name concepts or phenomena that they associate with thermal conduction instead.

1. ✎ What is thermal conduction? Explain in your own words.

Key ideas that students are expected to know already:

- Thermal conduction is one of the three mechanisms of heat transfer
- Thermal conduction is the main mechanism of heat transfer in solid materials (although it can be occur in solid, liquid, and gas phases)

Advanced ideas that students are not yet expected to know:

- Thermal conduction occurs through microscopic collisions of particles in a material
- Thermal conduction requires a temperature difference

Ask students to list things that are made of metal / wood and what they are used for.

2. ✎ Are metals good at conducting heat? Where have you seen them being used? Is wood good at conducting heat? Where have you seen them being used?

Metals are generally good conductors and are commonly used in cookware.
Wood is a worse conductor than metal and can be used to make cup holders.

Additionally, ask students if they are familiar with the following terms: independent variable, dependent variable and control variable. Introduce the following mnemonic device to help students memorize them:

3. **In**dependent variable is what's **in**troduced into the experiments
4. **D**ependent variable is the **d**ata being collected
5. **Control** variables are kept **con**stant across all experiments

6. ✎ How can you design an experiment to find out which one is a better thermal conductor?

By designing an experiment. Key components of the experiment include:

- The independent variable should be the type of material
- The dependent variable should be the temperature change

- The controls should include the temperature difference (i.e., same ambient temperature and same heat source), the size of the materials, and the duration of thermal contact

Experiment 1.1: Two Thumbs Up!

Preparation (Lab Host)

- Place the two rulers side by side on a flat non-reflective surface: wooden ruler on the left; metallic ruler on the right.
- Connect the IR camera to the phone.
- Connect the power bank to the IR camera.
- Setup the phone stand such that the IR camera (now connected to the phone) is directly above the rulers.
- Open the Infrared Explorer app on the Android phone.
- Turn on the IR camera and wait for the indicator light to flash green.
- Adjust the view of the camera so that the rulers appear at the center.
- In Infrared Explorer, turn on visible light mode (View -> Visible).
- In Infrared Explorer, connect to Telelab (⋮ -> Connect Telelab -> Combined).
- **Lab host** will announce the Telelab room number and post it in the video conference.
- **Lab host** will share their screen through the video conference to help students log onto Telelab and enter the live room.
- **Lab host** will wave their hand under the IR camera and confirm with students that they can all see the camera feed correctly.

Prediction

Copy and paste the bold question into the Telelab chat. Ask students to both respond in the Telelab chat and indicate their answer on their answer sheet. As student responses appear in the chat, ask students to explain their choice.

7. 🖌️ **If metal conducts heat better than wood, what do you expect to observe, after the two thumbs have touched each of them for one minute?** Highlight your prediction of the temperature at each of the three different positions on the rulers.

Position on ruler: high

A. $T_1 < T_4$
B. $T_1 = T_4$
C. $T_1 > T_4$

Position on ruler: middle

A. $T_2 < T_5$

B. $T_2 = T_5$
C. $T_2 > T_5$

Position on ruler: low

A. $T_3 < T_6$
B. $T_3 = T_6$
C. $T_3 > T_6$

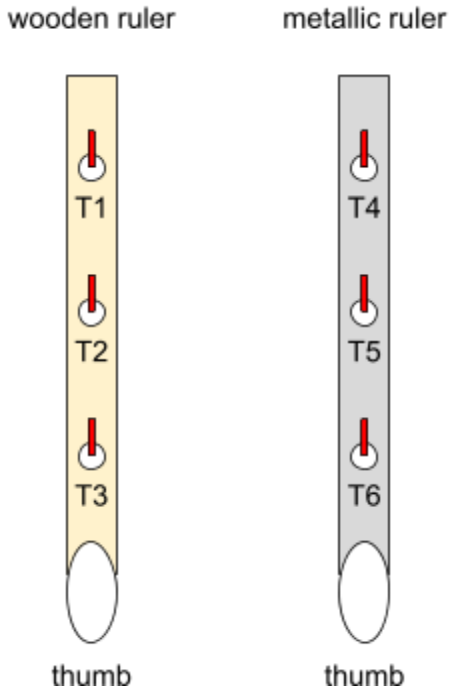


Figure 1. Experiment 1.1 setup

Data Collection (Lab Host)

- In Infrared Explorer, turn on blended mode (View -> Blended) and the temperature vs. time graph (Analyze -> T(t)).
- Add 3 thermometers to the upper, middle, and lower section of each ruler, respectively, so that there are 6 thermometers in total (see Figure. 1).
- **Lab host** tells students to add thermometers to the same places and also turn on the T(t) graph.
- **Lab host** confirms with students that their current temperature readings are stable.
- **Lab host** tells students to take a screenshot of the initial temperature readings and the T(t) graph.

- **Lab host** tells students that they will need to take another screenshot in 60 seconds and they will be given the notice to do so when it comes time. They should feel free to focus on any part of the Telelab interface - the thermogram, thermometer readings or the T(t) graph - once the experiment begins.
- Start both the experiment and recording on the count of 3.
- Once recording starts, put the left thumb on the bottom of the wooden ruler (on the left) and the right thumb on the bottom of the metallic ruler (on the right). Press slightly to ensure there is heat conduction between the thumbs and the rulers.
- After 60 seconds, **lab host** tells students to take another screenshot.
- Wait another 15 seconds and stop recording.

Observation and data analysis

Direct students to their worksheet. Allow some time for students to insert the two screenshots from earlier and fill out the data table.

8. 📸 Take a screenshot before the thumbs touch the rulers, and take another screenshot after the thumbs have touched the rulers for 60 seconds.

In a Telelab live room,

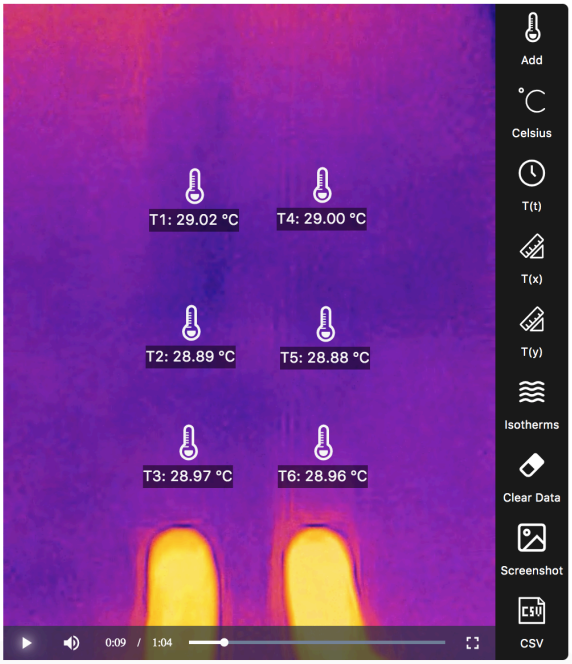
Click or drag to add a thermometer;

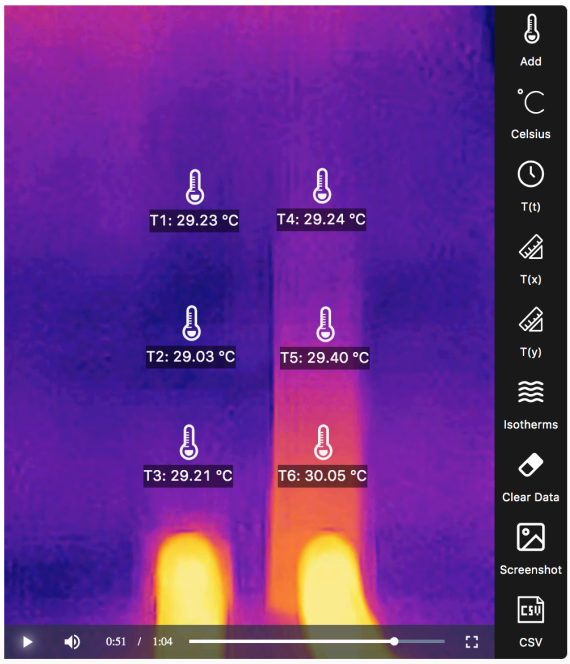

Click and drag any thermometer to the bin to delete it;

Click to plot temperature against time;

Click to take a screenshot.

Screenshot at time = 0s	*Screenshot at time = 60s*





9. ✎ Use the screenshots to fill out the white columns below, then calculate results for the yellow column.

Temperature (℃) at t=60s	Wooden ruler, T_w	Metallic ruler, T_m	Temperature difference, T_w-T_m
Position on ruler: high	29.2	29.2	0
Position on ruler: middle	29.0	29.4	-0.4
Position on ruler: low	29.2	30.0	-0.8

Explanation

Discuss the following questions with students before asking them to write down their answers in the worksheet.

Additionally, ask students to compare the results with their predictions and if their predictions happen to be incorrect, ask them to reflect why they think the results are different than what they predicted.

10. ✎ What can you conclude about the conductivity of metal and wood from the table above? What evidence can you use to support your conclusion?

Metal conducts heat better than wood. The evidence is that after the rulers have been in contact with the same heat source for the same amount of time, the metallic ruler is warmer everywhere than the wooden ruler.

Encourage students to share their ideas and guesses with the class. Allow students to finish sharing even when their ideas are not perfect, and aim at collecting a diverse mix of (conflicting) ideas to both pique students' curiosity and create opportunities for learning afterwards.

11. ✎ How does your conclusion above help us explain why the metallic ruler feels cooler than the wooden one? Where else can we measure temperature in the "Two Thumbs Up" experiment? Choose any number of options from Figure 2 and explain why measuring them helps you explain why metal feels colder than wood.

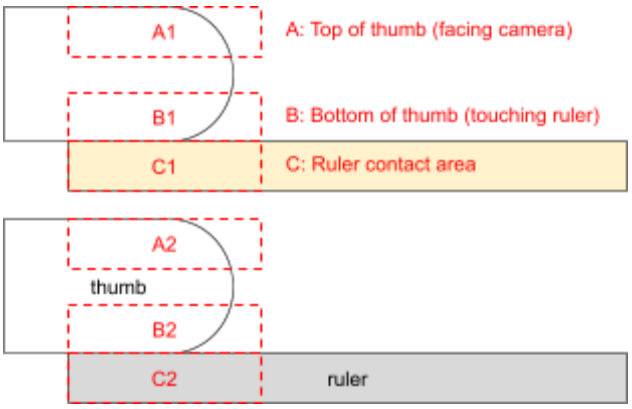


FIgure 2. A side view of the "Two Thumbs Up" experiment

One hypothesis of why metal feels colder than wood could be that the metal ruler simply has a lower temperature than wood after being touched by the thumb, and therefore C2 will be cooler than C1. However, this hypothesis seemingly contradicts the fact that metal is a better conductor than wood, which could lead one to believe that its temperature will increase more after being touched by the thumb. So, measuring C1 and C2 is a good way to test this hypothesis.

Another hypothesis could be that metal feels colder because it absorbs more heat from the thumb, leaving the skin at a lower temperature, which is then registered as a feeling of coldness by the nerve endings on the skin. Measuring B1 and B2 will allow us to test that.

Ask students to take some time to think about what they expect to see, if they were to measure the temperatures of areas A/B/C. Ask students to either share their predictions with the class or write them down in their worksheets. Do not correct students if their predictions are incorrect; instead, give students an opportunity to find out through the experiment themselves and self-correct their mental models about heat conduction before intervening.

12. ✎ After you've chosen where to measure the temperature on both rulers/thumbs, how will the measurements compare between the metallic ruler and the wooden ruler? Briefly explain your predictions.

The **correct** predictions are:

Area (A/B/C)	*Prediction*	*Reasoning*
C	C1 > C2	...because heat is conducted away from the near end towards the far end at a higher speed
B	B1 > B2	...because more heat is conducted from the thumb to the ruler

Students may also come up with **incorrect** predictions such as:

Area (A/B/C)	*Prediction*	*Reasoning*
C	C1 < C2	...because more heat is conducted from the thumb to the ruler
B	B1 = B2	...because the human body is a heat reservoir

Experiment 1.2: Two Thumbs Up...Again!

Data Collection (Lab Host)

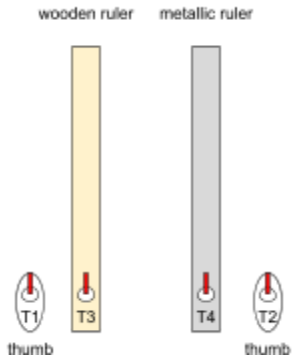
- In Infrared Explorer, turn on blended mode (View -> Blended) and the temperature vs. time graph (Analyze -> T(t)).
- Add 3 thermometers to the upper, middle, and lower section of each ruler, respectively, so that there are 6 thermometers in total (see Figure. 1).
- **Lab host** tells students to add thermometers to the same places and also turn on the T(t) graph.
- **Lab host** confirms with students that their current temperature readings are stable.
- **Lab host** tells students to take a screenshot of the initial temperature readings and the T(t) graph.
- **Lab host** tells students that they will need to take another screenshot in 60 seconds and they will be given the notice to do so when it comes time. They should feel free to focus on any part of the Telelab interface - the thermogram, thermometer readings or the T(t) graph - once the experiment begins.
- Start both the experiment and recording on the count of 3.
- Once recording starts, put the left thumb on the bottom of the wooden ruler (on the left) and the right thumb on the bottom of the metallic ruler (on the right). Press slightly to ensure there is heat conduction between the thumbs and the rulers.
- After 60 seconds, **lab host** tells students to take another screenshot.
- Wait another 15 seconds and stop recording.

Observation and data analysis

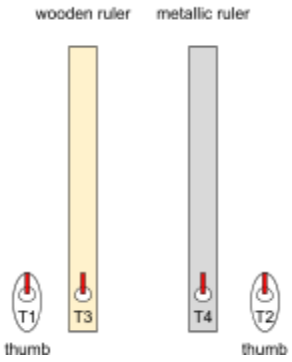
Direct students to their worksheet. Allow some time for students to insert the two screenshots from earlier and fill out the data table.

13. 📸 Observe the same experiment again. This time, collect temperature data at the bottom of the thumbs and the contact area on the rulers (B and C from Figure 2).

Screenshot at time = 0s, with the two thumbs away from the rulers and facing the IR camera	Screenshot at time = 60s, with the two thumbs away from the rulers and facing the IR camera



Your screenshot should look like this. Replace the image above with your actual screenshot.



Your screenshot should look like this. Replace the image above with your actual screenshot.

14. ✎ Use the screenshots to fill in the white blanks and calculate results for the yellow blanks.

Temperature (℃)	Wooden ruler, T_w	Metallic ruler, T_m	Temperature difference, T_w-T_m
Ruler contact area, t=0s	28.9	28.9	0
Ruler contact area, t=60s	31.7	30.5	+1.2
Temperature change of ruler	+2.8	+1.6	
Thumb before contact, t=0s	33.3	33.3	0
Thumb after contact, t=60s	31.9	30.7	+1.2
Temp. change of thumb	-1.4	-2.6	

Explanation

Discuss the following questions with students before asking them to write down their answers in the worksheet.

15. ✎ Why does the contact area on the metallic ruler have a lower temperature than the contact area on the wooden ruler?

Heat conduction in this experiment actually consists of two steps. First, heat is conducted from the thumb to the contact area on the ruler. Second, heat is conducted from the near end of the ruler to the far end. The lower temperature of the contact area on the metallic ruler suggests that any heat accumulated locally at the contact area quickly dissipates along the metallic ruler, leaving the contact area at a lower temperature.

16. ✎ Why is this consistent with the fact that metal conducts heat better than wood?

The lower temperature of the contact area on the metallic ruler suggests that any heat accumulated locally at the contact area quickly dissipates along the metallic ruler, consistent with the fact that metal conducts heat better than wood. Therefore, it is possible for the metallic ruler to absorb just as much heat, if not more, from the thumb yet still maintain a lower temperature at the contact area than the wooden ruler.

17. ✎ Why does the thumb that has touched the metallic ruler have a lower temperature? Does this agree with the phenomenon that metal feels colder than wood? How does the energy transferred from the thumb to the metallic ruler compare with that transferred to the wooden ruler?

(Assuming the same specific heat, contact area, contact duration, and thickness of the two thumbs,) A lower temperature on the thumb means more heat/thermal energy is transferred from the thumb to the metallic ruler, which is the fundamental reason why metal feels colder than wood.

18. ✎ Can you combine all your observations so far and give a comprehensive explanation of why metal feels colder than wood?

Guiding question:	Why does metal feel colder than wood?
Claim:	Heat transfers faster from the thumb to the metal upon touching.
Evidence:	• Both rulers have the same initial temperature before being touched. • Temperature at the farther end of the metal ruler is higher than that of the wooden ruler after 1 minute of touching. • Temperature at the contact area between the thumb and the metal ruler is lower than that of the wooden ruler after 1 minute of touching. • Temperature of the thumb is lower after 1 minute of touching the metal ruler.

Reasoning:	• The two rulers have the same initial temperature, which rules out the possibility that metal feels colder because it has a lower temperature than wood
	• Metal conducts heat better than wood, as seen from the first round of observations, which actually has three implications
	  ○ First, a lower final temperature on the thumb touching the metal and a bigger temperature difference mean that the heat flux - the amount of heat transferred from the thumb to the metal per unit time and area - is greater
	  ○ Second, although more heat is transferred to the metal, it also dissipates faster in metal than in wood, leaving the contact area at a lower temperature
	  ○ The greater temperature difference between the thumb and the metal further increases the heat flux (note: this is supported by the equation of heat conduction, but it may not be obvious from existing experimental results, and students can be prompted to design a new experiment to verify this)
	• Together, this means the thumb loses heat much faster when it touches the metal, creating the sense of coldness