1 Compare Thermal Energy and Temperature

Unit Essential Question

How do we use and control thermal energy in a system?

Introduction

In the Culminating Project, the client is asking students to design a product that either minimizes the amount of thermal energy that transfers from one place to another (e.g., the glove and ice block projects) or maximizes the amount of heat that transfers (e.g., the cookie and hot tub projects). In this task, students will examine the meaning, relationship, and differences between temperature and thermal energy.

Objectives

Students will be able to

Content

- Explain the difference between thermal energy and temperature.

Science and Engineering Practices

- Construct an argument based on evidence.

Equity and Groupwork

- Make sure everyone contributes.

Language

- Communicate ideas and listen actively.
- Read the displayed ideas from each group and the Culminating Project.
- Use the academic vocabulary in ideas, discussions, and notes.
- Write their ideas in their science notebook and Individual Project Organizer.

Emerging →	Expanding →	Bridging →
Listen for, identify, and restate words and phrases about thermal energy and temperature. Ask and answer yes-no questions about the task. Respond using simple phrases.	Describe the task in sequence using words and phrases about thermal energy and temperature. Ask questions about the task and use complete sentences. Add information when possible.	Paraphrase and summarize the task in sequence using words and phrases about thermal energy and temperature. Ask questions about the task and use complete sentences. Affirm others, and build on their responses.

Assessment

1. Have students independently complete the Task 1 section of the Individual Project Organizer as homework or in class, depending on students' needs and/or class scheduling.
2. Collect and assess each student's Individual Project Organizer using the following criteria:
   - "Developing and Using Models" row of the Science and Engineering Practices Rubric
   - "Engaging in Arguments from Evidence" row of the Science and Engineering Practices Rubric
3. Return the Individual Project Organizers, and give students time to make revisions. ELLs may need additional time.

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Academic Vocabulary

- claim
- evidence
- heat
- kinetic energy
- observation
- particle
- potential energy
- reasoning
- temperature
- thermal energy
- transfer

Language of Instruction

- construct (e.g., write an argument)
- criteria
- fill in (e.g., complete a Data Table)
- inference
- prediction
- record (e.g., means to write)

Timing

This task can be completed in 4 class periods (based on 45-minute periods).

- Part I • Particles in Motion (2 class periods)
- Part II • Thermal Energy and Temperature (1 class period)
- Part III • Connect to the Culminating Project and Assessment (1 class period)

Teacher Materials

- “Energy Terms” digital slide presentation
- 250 mL beaker (for measuring hot and room temperature water)
- 50 mL beaker (for measuring hot and room temperature water)
- Measuring cup or beaker for ice (about $\frac{1}{2}$ c or 100 mL)
- 400 mL beakers (2, for ice and water combination)
- 2 plates to put the remaining ice on after 1 minute
- Room temperature water
- Hot water
- Ice
- Timer
- Strainer (to strain ice out of water)
- Hot plate and a pot or an electric tea kettle
- Vocabulary cards for the wall concept map (write each of the following words on an index card: heat, thermal energy, temperature, kinetic energy, particles)
- Tape or magnets to hold vocabulary cards on wall or board

SAFETY NOTE

Heat water to a safe temperature. Boiling water will melt plastic cups and may cause burns.

Background Knowledge

In this task, students will represent matter at the particle level using particle diagrams. Therefore, it will be helpful to introduce students to the particulate nature of matter.

The focus of this task is on thermal energy and temperature. *Heat* is a term often overused and used improperly. As a result, the goal is to focus students on the terms *temperature* and *thermal energy*.

The following chart distinguishes between temperature, thermal energy, and heat.

Term	Definition	Example (using a swimmer in an ocean analogy)
Temperature	Temperature is the **average** internal kinetic energy in a system.	The swimmer has a temperature of 37°C (98.6°F). The ocean has a temperature of 15.6°C (60°F).
Thermal Energy	Thermal energy is the **total** internal kinetic energy of a system.	There is more thermal energy in the ocean than in the swimmer because the ocean is bigger (has more mass) than the swimmer.
Heat*	Heat refers to the energy transferred between two objects due to the difference in temperature between the two objects. Heat travels from warm to cold.	The heat transfers from the swimmer to the ocean because the swimmer has a higher temperature than the ocean.

*For reference only

STUDENT CONNECTION

Some students will be more familiar with Celsius temperatures. When sharing the examples, mention the difference between Fahrenheit and Celsius degrees. Explain that F represents Fahrenheit and C represents Celsius. A small circle symbol is used to represent degrees. Offer one example: Using the Fahrenheit scale, the temperature of the human body is 98.6°F; using the Celsius scale, the temperature is 37°C. Ask students when or where they have seen temperature used, and ask how it was measured (e.g., an oral thermometer when they were sick; in cooking; for the weather).

Part I • Particles in Motion

The purpose of this activity is to help students understand the meaning of kinetic energy, temperature, and thermal energy. You can mention phase change (ice, liquid, and gas), but do not make this the focus of the simulation. The focus is on the change of the speed of the particles in different temperatures and is intended to help students figure out and internalize the relationships between kinetic energy, temperature, and thermal energy.

1. Set up the PhET simulation (https://phet.colorado.edu/en/simulation/gas-properties).
   Set to:
   - Constant Parameter: Volume
   - Gas in Chamber: Heavy Species/50 particles
   - Gravity: 0
   - Heat: 0
2. Arrange students' desks into a large circle or square so that students are in an enclosed "container" and can act like particles in motion within the container. (This can be done before students enter class or after you model the activity.)
3. Write the words *particle*, *kinetic energy*, *temperature*, and *thermal energy* in a place where you can point to the terms regularly during the task—on chart paper posted on the wall or on a white board.
4. Model the activity and energy words (particle and kinetic energy).
   a. Select a student volunteer. Model particle movement and particle collision with the student volunteer. You and the student should move faster and slower in a safe way. Collide with the student by touching hands to model safe collisions.
   b. Explain that you and the student volunteer are particles with kinetic energy (energy of motion) as you move around. Point to the words *particle* and *kinetic energy*.
5. Have students do the activity.
   a. Ask students to get up and be particles with kinetic energy. Students should move slowly around the space within their desks. Let them practice moving and colliding safely.
      - Ask students to raise their hand if they are a particle. (Everyone should raise their hand.)
      - Ask students what they are. (Everyone should say "particles.")
      - Ask students what type of energy each one has right now as they are moving. (Everyone should say "kinetic energy.")
      - Ask students to stop moving. Ask if anyone knows what type of energy they have when they are stopped. (Someone might know the term *potential energy*).
      - Ask students to be particles with kinetic energy and then potential energy over and over (students should move and stop and move and stop). Be tricky and say "kinetic energy" twice in a row.
      - Ask students to say what type of energy they have when they move (kinetic energy) and to say what type of energy they have when they stop (potential energy).

   b. Have students get into potential energy position (stop) for a moment. Show students the PhET simulation.
      - Ask students what they see. (Students should respond with "particles with kinetic energy." They may make other observations as well, which is fine.)
      - Tell students that they are going to mimic (copy) what happens in the PhET simulation.

   c. Have students start to mimic the PhET simulation.
      - Point out that the simulation shows particles moving with kinetic energy.
      - Ask again what they (the students) are and what type of energy they are using. (particles and kinetic energy)

d. Remove most of the “heat” in the simulation. The particles should start to move more slowly. Ask students to mimic what would happen in a cold environment.

- Ask students if they have more or less kinetic energy when the temperature gets colder. (less kinetic energy)
- Ask students to raise their hand if they are a particle. (Everyone should raise their hand.)
- Ask students if they are representing cold or hot right now. (cold)

e. Introduce the word *temperature*. Reset the simulation (medium temperature) and ask students to mimic the new speed of the particles using the appropriate kinetic energy. (All students should be moving at medium speed.)

- Point out the thermometer in the simulation. Tell students that the thermometer is measuring temperature, which is the average amount of kinetic energy in the system, or the average amount of particle movement in the system.
- Reduce the heat in the simulation and ask students to mimic the lower temperature. Again point out the thermometer and how the temperature has gone down. Explain again that the thermometer is measuring the average kinetic energy in the system, or average amount of movement.
- Go back and forth between reduced heat and greater heat settings and ask students at each point whether there is
  - More or less kinetic energy
  - More or less temperature
- Ask multiple students to explain the terms *kinetic energy* and *temperature*.

f. Next, add heat to increase the temperature in the simulation. The particles move faster.

- Ask students to mimic the warmer temperature within their “container.”
- Ask students if they now have more or less kinetic energy than before. (more)
- Ask students to look at the thermometer. Has the temperature gone up or down? (up)
- Ask multiple students to remind you what temperature means.

g. Have students rotate through reduced (cold), medium, and greater (hot) temperatures. Mix up the settings until you feel that students have an understanding of temperature.

- When moving slowly, ask students what they are doing to show a cool temperature. (Students should say that the particles are on average moving slowly, or that most of the particles are moving slowly.)
- When moving at a medium speed, ask students what they are doing to show a medium temperature. (Students should say that the particles are on average moving at a medium speed, or that most of the particles are moving at a medium speed.)
- When moving at a fast speed, ask students what they are doing to show a hot temperature. (Students should say that the particles are on average moving at a faster speed, or that most of the particles are moving at a fast speed.)
- Ask students what they are and what type of energy they are using when they are moving. (They are particles, and they are using kinetic energy.)

h. Introduce the word *thermal energy.* Reduce the heat in the simulation to a cold temperature.

- Define thermal energy as the total amount of kinetic energy in a system.
- Ask students to mimic the cold (reduced temperature) particle movement.
- Tell students that all the kinetic energy right now is thermal energy. Basically, if you added up all the movement, that would be the thermal energy.
- Increase the simulation to medium temperature. Have students mimic the correct particle movement now. Ask students how they are representing thermal energy. Ask students if they have more or less thermal energy than in the cold simulation. (more)

- Increase the simulation to high temperature. Have students mimic the correct particle movement now. Ask students how they are representing thermal energy. Ask students if they have more or less thermal energy than when they were moving at a medium speed. (more)
- Repeat until you feel that students have an understanding of thermal energy.

i. Have students do a different thermal energy example. Reset the simulation to medium heat.

- Ask students to mimic the movement in the simulation.
- Repeat the definition of thermal energy as the total amount of kinetic energy in a system.
- Tell students that they all represent the total amount of kinetic energy in the "container."
- Ask one student at a time to sit down as you reduce the number of particles in the simulation. Explain that by reducing the number of particles you are reducing the total amount of kinetic energy in the system, so you are reducing the total amount of thermal energy.
- Start adding particles to the simulation and ask students to stand up again one at a time.
- Asks students what is happening to the amount of thermal energy in the system. (increasing because there are more particles)
- Ask students what is happening to the temperature. (stays the same because the particles are moving at the same speed, even if there are more particles)
- Repeat until students have an understanding of thermal energy.

j. Review once more the words *particle*, *kinetic energy*, *thermal energy*, and *temperature*.

- Ask students to be a particle.
- Ask students to represent kinetic energy.
- Ask students to represent a cold temperature.
- Ask students to represent a hot temperature.
- Ask students to represent a lot of thermal energy.
- Ask students to represent a little bit of thermal energy.

k. Have students return to their desks.

l. Optional: Reset the PhET simulation and make temperature the constant parameter with 50 heavy species. Move the box handle left and right to make the box larger and smaller and ask students what is happening. (The kinetic energy may change, causing a temporary temperature change, but the thermal energy always stays the same because the number of particles stays the same.)

6. Have students work on Part I steps 2–4 in small groups. You may want to suggest that students copy their sentences from step 4 into their science notebook for reference throughout the unit.

ELL SCAFFOLD

Before students meet for the group discussion, prepare them for the discussion by connecting what they viewed in the PhET Gas Properties simulation and what they acted out to the terms *thermal energy*, *kinetic energy*, and *temperature*. Offer sentence frames to support oral discussion about particles in motion.

Emerging →	Expanding →	Bridging →
My movement changed by ____. I had ____ (more, less) kinetic energy. One way we can show the particles moving faster or slower is to ____.	After thermal energy was added to the system, my movement changed when ____. There was ____ (more, less) kinetic energy. In the diagram, we can show how the particles move slower or faster by ____.	After thermal energy was added to the system, there was a change in movement because ____. There was ____ (more, less) kinetic energy because ____. Another way to show how the particles move slower or faster in our diagram would be to ____.

7. Debrief steps 2–4 as a whole class. Keep language and equity objectives in mind. Step 2a: How did the movement of particles change after the temperature was increased? (particles moved faster)
   - Step 2b: Was there more or less kinetic energy after the temperature was increased? (more)
   - Step 3: Allow students to use their creativity in their drawings. Many times students show the faster particles with longer arrows attached to them and the slower particles with shorter arrows attached to them. Encourage students to share their diagrams.
   - Step 4: Use the digital slide presentation to go over the vocabulary in the table. Encourage students to share their answers. Probe for explanations as to why students wrote their sentences the way they did. Below are sample sentences.
     - Ice is made up of water particles.
     - A jet plane has more kinetic energy than a car.
     - The swimmer’s temperature is higher than the temperature of the Pacific Ocean.
     - The Pacific Ocean has more thermal energy than the swimmer.
     - The fire’s thermal energy transferred to the marshmallow and warmed the marshmallow.

Part II • Thermal Energy and Temperature

The purpose of this activity is to reinforce the idea that thermal energy depends on the number of particles, while temperature does not, and to have students apply the concepts of thermal energy and temperature to a real-world situation.

1. Set up the materials for the teacher demonstration.
2. Organize students in groups at tables for group discussion between demonstrations.
3. Review the general procedures for the three demonstrations. Explain that the variables that will change are the **temperature** of the water and the **amount** of water that will be added to the ice.
4. Discuss the first three group discussion questions. These questions focus on the idea of a "fair test" (everything stays the same except one variable; then, if there are differences in the results, the results are due to the one variable that was different).
5. Explain that before each demonstration, students will make a prediction.
6. Review the Data Table expectations before starting the first demonstration.

ELL SCAFFOLD

Clarify the language of instruction on the student page—e.g., prediction, reason, record (in this case, the meaning is "to write").

7. Review the procedure for Demonstration 1.
8. Give students time to make a **prediction** and record it in the Data Table.
   - Remind students that their predictions do not have to be the same as those of other members in their group. Each student may have a different idea as to what may happen and why.
   - Option: Ask students to stand up and go to one side of the room if they think the ice in Cup 1 will melt faster and go to the other side of the room if they think the ice in Cup 2 will melt faster. Ask students to explain their predictions, but don't give any clues as to who is right or wrong.
9. Conduct the demonstration.
   - Prepare the ice cups.
   - Prepare the two beakers of water.
   - Ask for two student volunteers to help pour the water at the same time.
   - Ask for a student volunteer to time 1 minute from the time the water is poured into the ice.
   - Have the two volunteers pour the beakers of water onto the cups of ice at the same time. The third volunteer should start the timer.
   - After 1 minute, strain the unmelted ice out of the cups and put the ice on two different plates.
10. Allow time for groups to discuss what they observed during the demonstration and fill in the Data Table.

ELL SCAFFOLD

Offer sentence frames to prompt oral answers about students' observations and what they recorded in their Data Table.

- I predicted that both cups would melt the same.
- Cup ____ (1, 2, 1 and 2) melted ____ (faster, the same) because ____..

11. Debrief Demonstration 1. After discussing the results and the explanations for the results, ask for volunteers to quickly sketch two large diagrams showing what happened to the particles in the two cups.

12. Repeat steps 7−11 for Demonstrations 2 and 3.

Data Table Results			
	Prediction Which cup of ice will melt faster? (1, 2, or same)	**Results** Which cup of ice melted faster? (1, 2, or same)	**Reason** Explain the results. Review the definition of *thermal energy*. Remind students that thermal energy is the total amount of kinetic energy, so it is the amount of substance (number of particles) and temperature combined.
Demonstration 1 Cup 1: 200 mL Hot Water Cup 2: 200 mL Room Temperature Water		1	Even though the same amount of water was added to each cup, there was more thermal energy in Cup 1 because the temperature (kinetic energy) was greater.
Demonstration 2 Cup 1: 200 mL Room Temperature Water Cup 2: 20 mL Room Temperature Water		1	Even though the water added to the two cups was the same temperature, there was more thermal energy in Cup 1 because there was more water.
Demonstration 3 Cup 1: 200 mL Room Temperature Water Cup 2: 20 mL Hot Water		1, 2, or same	This one is tricky. There was more water added to Cup 1, but it had less kinetic energy. There was less water added to Cup 2, but it had more kinetic energy. Because total thermal energy is determined by the amount of substance and its temperature, the two cups of water may have had equal amounts of thermal energy.

13. Have students complete the hot chocolate question as a group. Tell them to put their answer and drawing in their science notebook.

14. Debrief the hot chocolate question as a class.
    - Have groups share their diagrams on the board or on posters.
    - Possible **claim**: I think the large pot of hot chocolate has more thermal energy.
    - Possible **evidence**: I saw in Demonstration 2 that when you have two different amounts of a substance (water) at the same temperature, the larger amount (cup with more water) will melt the ice faster and thus has more thermal energy.
    - Possible **reasoning**: There are more particles of hot chocolate in the large pot of hot chocolate than in the small cup of hot chocolate. The temperature is the same. Since thermal energy is based on the total kinetic energy, which is the amount of particles and temperature combined, the large pot of hot chocolate has more thermal energy.

NOTE

Students have not actually done any activity about heat, but they might recognize that the thermal energy transferred from the water (hotter) to the ice (colder).

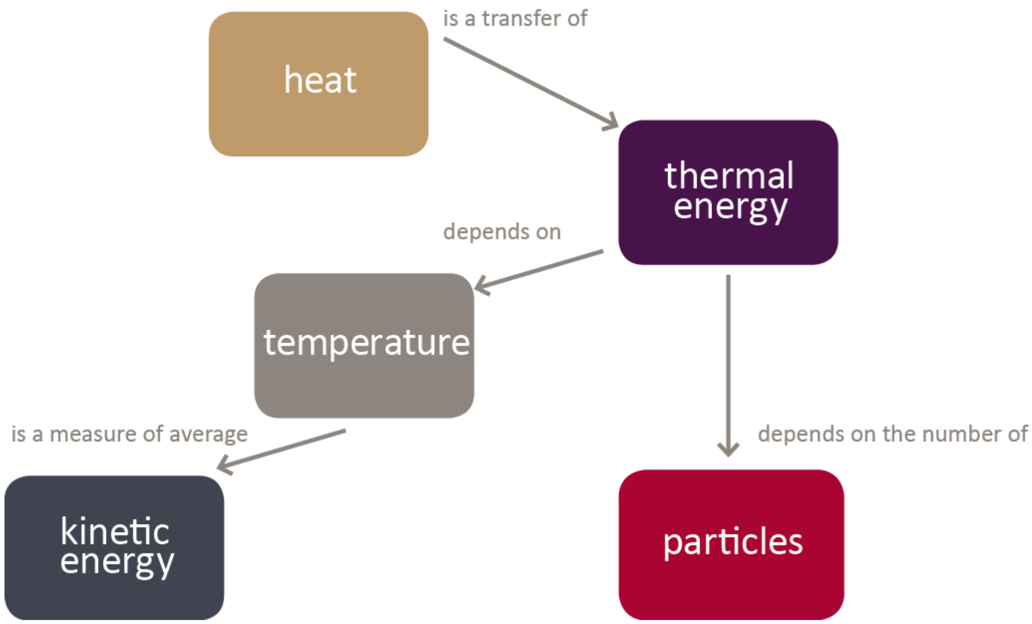
15. Introduce the energy concept map by writing two or three related terms that are not scientific and ask how they are related. For example, you could ask, "What are the relationships between these terms: phone, person, and money?" Draw arrows to connect the terms and form a sentence using all three words.

16. Then follow one of the three procedures below.
    - Place the five concept map vocabulary word cards on the board with tape or magnets and work through the concept map with the class.
    - Give groups the words in the concept map below on individual cards. Ask students to pull out two cards at a time and then discuss the relationship between the two words. They can return the two cards, mix up the cards, and pick two more cards, repeating this activity several times. After a certain amount of time (enough time to let students discuss five to six relationships), have each group create a concept map as a group first and then do the map as a class.
    - Complete the concept map for the energy-related terms as a class, asking "What is the relationship between _____ and _____?"

ELL SCAFFOLD

Have ELLs say the words as they are creating the concept map and state the relationship within the sentence. Provide an example: "Temperature is a measure of the average amount of kinetic energy in the system." Encourage them to look back at their student page with the definitions of the energy terms.

Keep the concept map on the wall or board and continue to return to it throughout the unit.



Part III • Connect to the Culminating Project and Assessment

1. Have students independently complete the Task 1 section of the Individual Project Organizer as homework or in class, depending on students' needs and/or class scheduling.

2. Collect and assess each student's Individual Project Organizer using the following criteria:
   - "Developing and Using Models" row of the Science and Engineering Practices Rubric
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3. Return the Individual Project Organizers, and give students time to make revisions. ELLs may need additional time.