ASPECt
Assessing Students' Progress on the Energy Concept

Thawing Soup: AP48-4 (CR) & AP61-3 (MC)

High School - Thermal Energy Transfer

TASK OVERVIEW

Students are presented with a scenario involving a chef who would like to figure out the best way to thaw small batches of soup. The students start by predicting how the amount of energy the soup and water have will change as a bag of frozen soup sits in a pot of 10 °C water. Students are told that the soup is still frozen after five minutes, and they are asked to use energy ideas to explain why the soup did not thaw. Finally, they analyze data from two different containers to determine which container will increase the temperature of the soup more and use ideas about energy transfer to justify their selection.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.5: 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).
- PS3.B-H.4: The availability of energy limits what can occur in any system.

Science & engineering practices

- SEP4-H.6: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.

Crosscutting concepts

- CCC2-M.2: Cause and effect relationships may be used to predict phenomena in natural or designed systems.
- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

Related Performance Expectations

- HS-PS3-4. Plan and conduct an investigation to provide evidence that the transfer of thermal energy when two components of different temperature are combined within a closed system results in a more uniform energy distribution among the components in the system (second law of thermodynamics). [*Clarification Statement*: Emphasis is on analyzing data from student investigations and using mathematical thinking to describe the energy changes both quantitatively and conceptually. Examples of investigations could include mixing liquids at different initial temperatures or adding objects at different temperatures to water.] [*Assessment Boundary*: Assessment is limited to investigations based on materials and tools provided to students.]

TASK PERFORMANCE EXPECTATION

Apply scientific ideas about the transfer of energy and the availability of energy within a system to (1) *explain* that combining two components at different temperatures within a closed system results in a more uniform energy distribution and (2) *explain why* an object does not thaw in a system that it is part of, if that system has a uniform energy distribution. *Analyze temperature data to* describe changes in energy in terms of energy flows into, out of, and within a system. *Identify patterns* of performance of two systems to identify which system will cause the temperature of a frozen object to increase more, and *apply scientific ideas* about the transfer of energy and the availability of energy *to justify the selection*.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/610

Task

A chef prepares a large batch of soup. He divides it into smaller batches that he freezes until he is ready to serve them.

Photo by Commander, U.S. 7th Fleet on flickr / CC-BY-SA-2.0

To thaw the frozen soup, he places a bag of frozen soup (-10 °C) into a metal pot of cool water (12 °C) and covers it.

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1. Using ideas about energy transfer, predict how the energy of the bag of soup and the surrounding water will change as the bag of soup sits in the pot of 12 °C water.

    A. The amount of energy the soup has will stay the same, and the amount of energy the water has will decrease until the water has the same amount of energy as the soup.

    B. The amount of energy the soup has will increase until the soup has the same amount of energy as the water, and the amount of energy the water has will stay the same.

    C. The amount of energy the soup has will increase, and the amount of energy the water has will decrease until they have the same amount of energy.

D. The amount of energy the soup has will increase, and the amount of energy the water has will decrease but they will never have the same amount of energy.

After five minutes, the chef looks at the bag of soup and notices that most of it is still frozen. He takes the temperature of the soup and water and finds that they are both at 0 °C. He decides to wait another five minutes and looks again. After ten minutes, most of the soup is still frozen, and both the water and the soup are still at 0 °C.

2. Use ideas about energy transfer to explain why the water did not thaw the soup completely.

The chef wonders what effect using a Styrofoam container would have on the temperature change of the water and soup. He fills the metal pot and a Styrofoam box with warm water that is 33 °C and then places a bag of frozen soup at -10 °C in each container.

Metal pot

Styrofoam box

He takes the temperature of the water, soup, and air right outside of the containers every 5 minutes for 20 minutes.

	Metal pot system			Styrofoam box system		
Time	Temp. of water	Temp. of soup	Temp. of air outside container	Temp. of water	Temp. of soup	Temp. of air outside container
0	33	-10	20	33	-10	20
10	25	3	21	24	4	20
15	23	12	22	20	14	20
20	22	14	22	19	17	20

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3. What patterns of temperature change do you see in the data in the table for the metal pot system?

    A. The temperatures of the water and the air outside the metal pot stay the same and the temperature of the soup increases.
    B. The temperature of the water increases as the temperatures of the soup and the air outside the metal pot decrease.
    C. The temperature of the water decreases as the temperatures of the soup and the air outside the metal pot increase.
    D. The temperature of the water decreases as the temperature of the soup increases but the temperature of the air outside the metal pot stays the same.

----------Constructed-response Version of #4----------

4. Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the metal pot system?

----------Multiple-choice Version of #4----------

4. Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the metal pot system?

    A. Energy is transferred from the soup to the water and from the air outside the metal pot to the water.
    B. Energy is transferred from the soup to the water and from the soup to the air outside the metal pot.
    C. Energy is transferred from the water to the soup and from the water to the air outside of the metal pot.
    D. Energy is transferred from the water to the soup but not from the water to the air outside of the metal pot.

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5. What patterns of temperature change do you see in the data in the table for the Styrofoam box system?

    A. The temperatures of the water and the air outside the Styrofoam box stay the same and the temperature of the soup increases.

B. The temperature of the water increases as the temperature of the soup and the air outside the Styrofoam box decrease.

C. The temperature of the water decreases as the temperatures of the soup and the air outside the Styrofoam box increase.

D. The temperature of the water decreases as the temperature of the soup increases but the temperature of the air outside the Styrofoam box stays the same.

----------Constructed-response Version of #6----------

6. Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the Styrofoam box system?

----------Multiple-choice Version of #6----------

6. Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the Styrofoam box system?

A. Energy is transferred from the soup to the water and from the air outside the Styrofoam box to the water.

B. Energy is transferred from the soup to the water and from the soup to the air outside the Styrofoam box.

C. Energy is transferred from the water to the soup and from the water to the air outside of the Styrofoam box.

D. Energy is transferred from the water to the soup but not from the water to the air outside of the Styrofoam box.

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7. Based on patterns you observed in the data, in which container does the temperature of the soup increase the most?

A. Metal pot

B. Styrofoam box

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8. Use the data in the table and what you know about energy transfer to explain why the temperature of the soup increases more in one container compared to the other.

Alignment to Targeted DCIs, SEPs, and CCCs and Scoring Rubrics

QUESTION 1

Using ideas about energy transfer, predict how the energy of the bag of soup and the surrounding water will change as the bag of soup sits in the pot of 12 °C water.

A. The amount of energy the soup has will stay the same, and the amount of energy the water has will decrease until the water has the same amount of energy as the soup.

B. The amount of energy the soup has will increase until the soup has the same amount of energy as the water, and the amount of energy the water has will stay the same.

C. The amount of energy the soup has will increase, and the amount of energy the water has will decrease until they have the same amount of energy.

D. The amount of energy the soup has will increase, and the amount of energy the water has will decrease but they will never have the same amount of energy.

LEARNING GOAL

Learning Performance

- Select a prediction about how the amounts of energy the bag of soup and warm water have will change when they are in contact.

Targeted DCIs, SEP, and CCC

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.5: 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).
- CCC2-M.2 Cause and effect relationships may be used to predict phenomena in natural or designed systems.

- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct prediction	C. The amount of energy the soup has will increase, and the amount of energy the water has will decrease until they have the same amount of energy.

QUESTION 2

After five minutes, the chef looks at the bag of soup and notices that most of it is still frozen. He takes the temperature of the soup and water and finds that they are both at 0 °C. He decides to wait another five minutes and looks again. After ten minutes, most of the soup is still frozen, and both the water and the soup are still at 0 °C.

Use ideas about energy transfer to explain why the water did not thaw the soup completely.

LEARNING GOAL

Learning Performance

- Use energy ideas to write an explanation for why the soup does not continue to get warmer when soaking in the water.

Targeted DCIs, SEP, and CCC

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.4: The availability of energy limits what can occur in any system.
- PS3.B-H.5: 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).

- SEP6-H.3: Apply scientific ideas, principles, and/or evidence to provide an explanation of phenomena and solve design problems, taking into account possible unanticipated effects.
- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

SCORING RUBRIC

Ideal Response

The soup did not thaw because there was not enough energy in the system. Energy will be transferred from the water to the frozen soup, causing the soup to increase in temperature and the water to decrease in temperature. The transfer of energy will stop when energy is uniformly distributed between the soup and the water. The amount of energy transferred from the water to the soup was enough for the temperature of the soup to increase to 0 degrees Celsius, but this was not enough energy to thaw the soup.

Elements of a Correct Response

Categories	Elements

Student makes a claim	• The soup did not thaw because
	  ○ there was not enough energy in the system or
	  ○ the water did not have enough energy or
	  ○ the water was not hot/warm enough.

Student either states or uses a general science idea	• Energy is transferred from hotter objects to cooler objects (i.e., from the warm water to the frozen soup). [*conduction*] • Uncontrolled systems always evolve toward more stable states (i.e., energy will be transferred from the water to the soup until the energy is evenly distributed). [*uniform energy distribution*] • The availability of energy limits what can occur in any system (i.e., there is not enough energy in the system to raise the temperature of the soup above its melting point). [*availability of energy*]

Student uses reasoning to link claim and science ideas	• Once the soup and the water reach the same temperature, the transfer of energy will stop and the soup will not receive enough energy to thaw.
Student does not discuss energy but has productive ideas about conduction	• Heat is transferred from the warmer water to the cooler soup until they are at the same temperature. [heat transfer]

Sample Student Responses

Student response	Scoring description
"The coldness of the soup transferred to the water"	Score = 0 The response includes the misconception that coldness is transferred from cold to warm objects.
"The water might not have been warm enough for the soup to thaw."	Score = 1 The response includes a claim but does not use science ideas and reasoning to support it.
"because there was not enough energy in the water to transfer to the soup making it warmer until both liquids were the same temperature."	Score = 2 The response includes a claim and the science idea about uncontrolled systems evolving toward more stable states, but it does not use reasoning to link the claim and science idea.
"The water did not thaw the soup completely because the water did not have enough energy to start. The water must be warm enough that it can transfer enough of its kinetic energy to the soup so that they both have the same energy and the soup is thawed. If the water does not have enough	Score = 3 The response includes all the elements in the rubric.

kinetic energy, the water can transfer less kinetic energy to the soup and therefore thaw it less. Temperature is the average measure of the kinetic energy of each particle in a substance. Kinetic energy is the movement energy of a particle or object."	

QUESTION 3

What patterns of temperature change do you see in the data in the table for the metal pot system?

A. The temperatures of the water and the air outside the metal pot stay the same and the temperature of the soup increases.

B. The temperature of the water increases as the temperature of the soup and the air outside the metal pot decrease.

C. The temperature of the water decreases as the temperatures of the soup and the air outside the metal pot increase.

D. The temperature of the water decreases as the temperature of the soup increases but the temperature of the air outside the metal pot stays the same.

LEARNING GOAL

Learning Performance

- Analyze the data in the table to identify patterns in the temperatures of the components in the metal pot system.

Targeted DCIs, SEP, and CCC

- SEP4-H.6: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
- CCC1-M.2: Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	C. The temperature of the water decreases as the temperatures of the soup and the air outside the metal pot increase.

QUESTION 4

Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the metal pot system?

LEARNING GOAL

Learning Performance

- Use patterns in temperature changes to make a conclusion about the energy transfer between the components of the metal pot system.

Targeted DCIs, SEP, and CCC

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.5: 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).
- SEP7-H.5: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
- CCC1-M.2: Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.
- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

SCORING RUBRIC

Ideal Response

Based on the patterns in the temperature data, I would conclude that energy was transferred from the water to the soup and from the water to the air outside of the metal pot.

Elements of a Correct Response

Categories	Elements
Student makes a claim	• Energy is transferred from the water to the soup. • Energy is transferred from the water to the air outside the metal pot.
OR	
Student selects the correct response to the multiple-choice version	C. Energy is transferred from the water to the soup and from the water to the air outside the metal pot.

Sample Student Responses

Note: The written responses were scored dichotomously. Students received a point if their response included both parts of the claim.

Student response	Scoring description
"What can be concluded is that the water on the inside released energy and made steam and also transferred energy into the soup trying to make it the same temperature."	Score = 0 The response includes the claim that energy is transferred from the water to the soup but does not include that the energy is also transferred to the air outside the pot.
"The metal pot water has a lot of energy that then main goes to the soup, yet it also is transferred to the surrounding air. This means the pot water will cool down, the	Score = 1 The response includes both elements in the rubric.

soup will heat up, and the surrounding air will heat up."	

QUESTION 5

What patterns of temperature change do you see in the data in the table for the Styrofoam box system?

A. The temperatures of the water and the air outside the Styrofoam box stay the same and the temperature of the soup increases.

B. The temperature of the water increases as the temperature of the soup and the air outside the Styrofoam box decrease.

C. The temperature of the water decreases as the temperatures of the soup and the air outside the Styrofoam box increase.

D. The temperature of the water decreases as the temperature of the soup increases but the temperature of the air outside the Styrofoam box stays the same.

LEARNING GOAL

Learning Performance

- Analyze the data in the table to identify patterns in the temperatures of the components in the Syrofoam box system.

Targeted DCIs, SEP, and CCC

- SEP4-H.6: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
- CCC1-M.2: Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	D. The temperature of the water decreases as the temperature of the soup increases but the temperature of the air outside the Styrofoam box stays the same.

QUESTION 6

Based on the patterns in the data, what can be concluded about the transfer of energy between the water, soup, and air in the Styrofoam box system?

LEARNING GOAL

Learning Performance

- Use patterns in temperature changes to make a conclusion about the energy transfer between the components of the Styrofoam box system.

Targeted DCIs, SEP, and CCC

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.5: 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).
- SEP7-H.5: Make and defend a claim based on evidence about the natural world or the effectiveness of a design solution that reflects scientific knowledge and student-generated evidence.
- CCC1-M.2: Patterns in rates of change and other numerical relationships can provide information about natural and human designed systems.
- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.

SCORING RUBRIC

Ideal Response

Based on the patterns in the temperature data, I would conclude that energy was transferred from the water to the soup but not from the water to the air outside the Styrofoam box.

Elements of a Correct Response

Categories	Elements
Student makes a claim	• Energy is transferred from the water to the soup. • Energy is NOT transferred from the water to the air outside the Styrofoam box.
OR	
Student selects the correct response to the multiple-choice version	D. Energy is transferred from the water to the soup but not from the water to the air outside of the Styrofoam box.

Sample Student Responses

Note: The written responses were scored dichotomously. Students received a point if their response included both parts of the claim.

Student response	Scoring description
"like the metal pot, the soap will start to increase and the water will transfer the energy to the soap."	Score = 0 The response includes the claim that the energy is transferred from the water to the soup, but it does not state that energy is not transferred to the air outside the pot.
"The water transfers energy to the soup. The air temperature does not change because there is no exchange in energy between it and the water due to the insulation from the styrofoam."	Score = 1 The response includes both elements in the rubric.

QUESTIONS 7 & 8

Based on patterns you observed in the data, in which container does the temperature of the soup increase the most?

A. Metal pot

B. Styrofoam box

Use the data in the table and what you know about energy transfer to explain why the temperature of the soup increases more in one container compared to the other.

LEARNING GOAL

Learning Performance

- Identify which contain raises the temperature of the soup more and then use energy ideas to support the claim.

Targeted DCIs, SEP, and CCC

- PS3.B-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- PS3.B-H.5: 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).
- PS3.B-H.4: The availability of energy limits what can occur in any system.
- SEP4-H.6: Analyze data to identify design features or characteristics of the components of a proposed process or system to optimize it relative to criteria for success.
- CCC5-H.2: Changes of energy and matter in a system can be described in terms of energy and matter flows into, out of, and within that system.
- CCC1-H.3: Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.

SCORING RUBRIC

Ideal Response

The temperature of the soup in the Styrofoam box increases more because more thermal energy stays inside the Sytrofoam box than inside the metal pot. The temperature change of the air outside the metal pot is evidence that energy is transferred from the warm water in the metal pot to the air outside the pot. In contrast, the temperature of the air outside the Styrofoam box did not have a measurable change. This indicates that little to no energy from the warm water is transferred out of the container. Therefore, there is more energy available to be transferred to the soup when using the Styrofoam box than when using the metal pot, which causes the temperature of the soup in the Styrofoam to increase more.

Elements of a Correct Response

Categories	Elements
Student selects the correct claim	B. Styrofoam box
Student cites relevant evidence	• The temperature of the air outside the Styrofoam box does not change and/or the temperature of the air outside of the metal box increases.
Student either states or uses a general science idea	• Changes in temperature are indicators of energy changes (i.e., if the temperature of the air doesn't change, it did not increase in thermal energy/no energy was transferred to the air). [*links energy and temperature*] • The availability of energy limits what can occur in any system (i.e., the more energy available in the box, the more the soup will increase in temperature). [*availability of energy*]
Student uses reasoning to link evidence and science ideas	• Because the temperature of the air outside of the sytrofoam box did not change, little to no energy is transferred out of the Styrofoam box, therefore, there is more energy available inside the box to raise the temperature of the soup.
Student does not discuss energy but has productive ideas about conduction	• More heat is available in the Styrofoam box than in the metal pot. [*heat transfer*]

Sample Student Responses

Student response	Scoring description
Student selected A and wrote: "The ending tempetures for the metal pot is higher then he styro foam box due to the amount of energy that is exerted."	Score = 0 The student selected the incorrect claim and did not provide a correct explanation.
Student selected B and wrote: "The temperature of the soup inside the Styrofoam box is higher because less heat is able to escape to the air around it."	Score = 1 The student selected the correct claim and their response includes productive ideas about heat transfer.
Student selected B and wrote: "Since the air stayed the same the entire time, it didn't slow down the process of the soup heating up."	Score = 2 The student selected the correct claim and cited evidence about the air staying the same temperature but did not support the claim with reasoning and science ideas about energy.
Student selected B and wrote: "The temperature of the soup increases more in the styrofoam container compared to the metal container because the metal container is highly conductive of heat. Because of this, the thermal energy is transferred not only to the soup but also to the air outside. The styrofoam box has all the thermal energy going to the soup and none to the air, so no heat is wasted. All the thermal energy goes to the soup allowing it to increase the temperature of the soup."	Score = 3 The student selected the correct claim and their response includes reasoning with science ideas, but it does not cite evidence.
Student selected B and wrote: "The temperature of the soup increases more in the styrofoam container because energy is not lost to the air (as the temperature of the	Score = 4 The student selected the correct claim and their response includes all the elements in the rubric.

air stats the same), allowing for more energy to be transferred from the water to the soup."	

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