ASPECt
Assessing Students' Progress on the Energy Concept

Spacecraft: AP05-8

Middle School – Thermal Energy

TASK OVERVIEW

Students are presented with a scenario in which a scientist is investigating two materials that are used as coatings to prevent spacecrafts from overheating when they re-enter Earth's atmosphere. They are provided with data on the temperature of one of the materials before and after it is heated and asked to calculate the change in temperature when it is heated. They also are asked to identify a pattern in the relationship between mass and change in temperature. They are asked to use ideas about the molecular scale to explain why the different masses had different temperature changes even though they had the same amount of energy transferred to them as they were heated. Students then analyze data on the second material and are asked to graph the change in temperature as a function of mass for both materials. Lastly, students identify patterns in how the two materials compare in their ability to prevent spacecrafts to overheat when they re-enter Earth's atmosphere.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- PS3.A-M.5: 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.

- PS3.B-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- PS1.B-M.2: The total number of each type of atom is conserved, and thus the mass does not change.

Science & engineering practices

- SEP4-M.1: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
- SEP6-M.1: Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.
- SEP5-M.4: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

Crosscutting concepts

- CCC1-M.4: Graphs, charts, and images can be used to identify patterns in data.
- CCC1-M.1: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

Related Performance Expectations

- MS-PS3-4. Plan an investigation to determine the relationships among the energy transferred, the type of matter, the mass, and the change in the average kinetic energy of the particles as measured by the temperature of the sample. [*Clarification Statement*: Examples of experiments could include comparing final water temperatures after different masses of ice melted in the same volume of water with the same initial temperature, the temperature change of samples of different materials with the same mass as they cool or heat in the environment, or the same material with different masses when a specific amount of energy is added.] [*Assessment Boundary*: Assessment does not include calculating the total amount of thermal energy transferred.]

TASK PERFORMANCE EXPECTATION

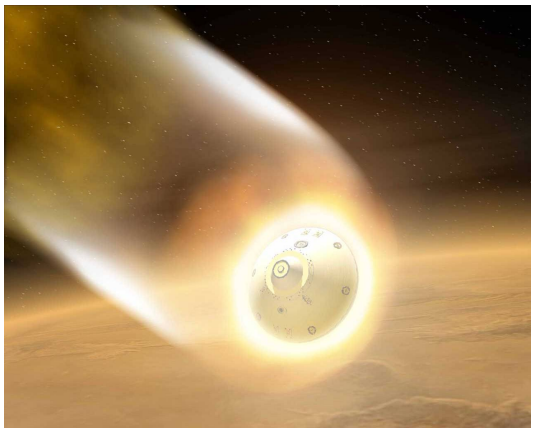
Apply mathematical concepts to identify patterns. *Explain trends in data*, observed at the macroscopic scale, using energy concepts and relationships applied at the molecular scale. *Construct a graph* of temperature data and identify patterns to describe the performance of different materials.

LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/608

Task

As a spacecraft re-enters Earth's atmosphere, it gets very hot. To minimize how much the spacecraft's temperature changes, engineers use materials that have small temperature changes when they are heated.



Artistic rendition of atmospheric entry of Mars Exploration Rover, NASA Jet Propulsion Laboratory

An engineer has developed a new ceramic material. She wants to know if it has a smaller change in temperature when heated than the graphite material already used on spacecrafts.

First, she performs an experiment to measure the change in temperature of graphite when it is heated. She creates three graphite samples of different masses: 400 grams, 600 grams, and 800 grams. She measures each sample's starting temperature. Then she heats each sample so that the same amount of energy is transferred to each sample. After heating them until the temperature has stopped changing, she measures each sample's temperature again.

The table below summarizes the data from her experiments with graphite.

	Graphite		
Mass of the samples in grams	400	600	800
Temperature **before** heating	20° C	20° C	20° C
Temperature **after** heating	180° C	130° C	100° C

1. Calculate the change in temperature for each graphite sample by comparing its temperature before and after heating.

	Graphite		
Mass of the sample in grams	400	600	800
Change in Temperature			

2. Using the data table you created, which of the following best describes the relationship between the mass of the sample and the change in temperature?
   A. As the mass of the samples increased, the change in temperature of the samples **increased**.
   B. As the mass of the samples increased, the change in temperature of the samples **decreased**.
   C. As the mass of the samples increased, the change in temperature of the samples **stayed the same**.
   D. As the mass of the samples increased, the change in temperature of the samples sometimes **increased**, and sometimes **decreased**.

The engineer wants to explain why the graphite samples had different changes in temperature even though they were heated by the same amount. She starts by thinking about the number and speed of the atoms and molecules that make up the samples.

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3. Which of the following best describes how the mass of a sample depends on the number of atoms and molecules that make up the sample?
   A. The more mass the sample has, the more atoms and molecules make up the sample.
   B. The more mass the sample has, the fewer atoms and molecules make up the sample.
   C. How much mass a sample has doesn't affect the number of atoms and molecules that make up the sample.

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4. Which of the following best describes how the temperature of a sample depends on the speed of the atoms and molecules that make up the sample?
   A. The faster the atoms and molecules that make up the sample are moving, the higher the temperature of the sample.
   B. The slower the atoms and molecules that make up the sample are moving, the higher the temperature of the sample.
   C. The temperature of a sample isn't affected by how fast the atoms and molecules that make up the sample are moving.

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5. Using what you know about the relationships between energy, temperature, and the number and speed of the atoms and molecules that make up the graphite samples, explain why the three graphite samples had different changes in temperature even though they were heated by the same amount.

Next, the engineer does the same set of experiments with samples of ceramic. Below is the table showing the temperature changes for the ceramic samples.

	Ceramic		
Mass of the samples in grams	400	600	800
Temperature **before** heating	20 °C	20 °C	20 °C
Temperature **after** heating	210 °C	150 °C	120 °C

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6. Calculate the change in temperature for each ceramic sample by comparing its temperature before and after heating.

	Ceramic		
Mass of the sample in grams	400	600	800
Change in Temperature			

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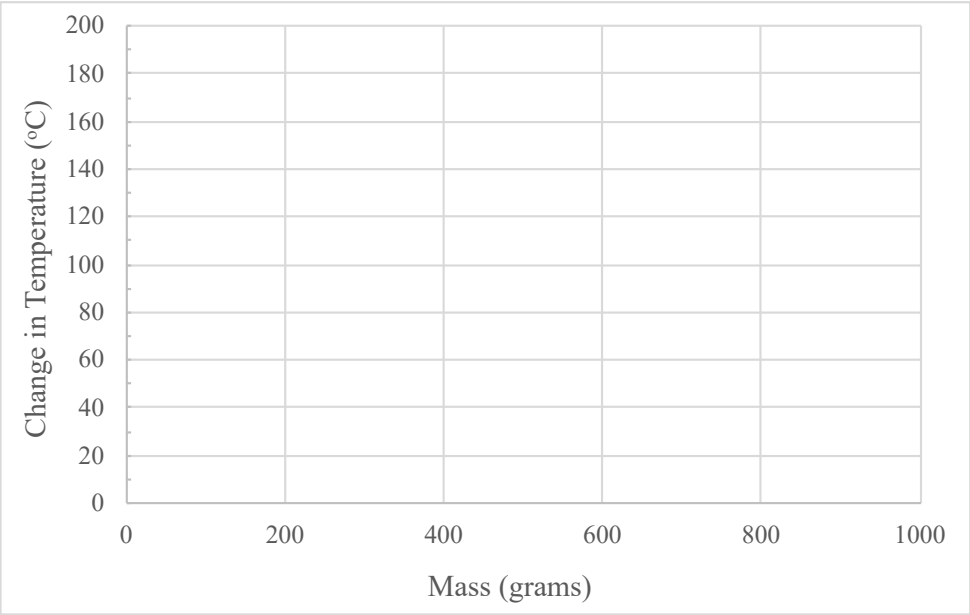
7. To better compare the data from the two sets of experiments, create a plot of the **mass of the samples** versus their **change in temperature**.

Your plot should include:

- Mass and change in temperature from both the graphite and ceramic experiments
- A plot legend labeling the graphite and ceramic data



8. Using the data tables above and the plot you created, which of the following best summarizes the change in temperature data from the two sets of experiments?
   A. When comparing samples with the same mass, ceramic always has a larger change in temperature than graphite.
   B. When comparing samples with the same mass, ceramic always has a smaller change in temperature than graphite.
   C. When comparing samples with the same mass, ceramic always has the same change in temperature as graphite.
   D. When comparing samples with the same mass, ceramic sometimes has a larger change in temperature than graphite, and ceramic sometimes has a smaller change in temperature than graphite.

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

QUESTION 1

	Graphite		
Mass of the samples in grams	400	600	800
Temperature **before** heating	20 °C	20 °C	20 °C
Temperature **after** heating	180 °C	130 °C	100 °C

Calculate the change in temperature for each graphite sample by comparing its temperature before and after heating.

	Graphite		
Mass of the sample in grams	400	600	800
Change in Temperature			

LEARNING GOAL

Learning Performance

- Use subtraction to determine the change in temperature of a material before and after being heated.

Targeted DCIs, SEP, and CCC

- SEP5-M.4: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

SCORING RUBRIC

Ideal Response

	Graphite		
Mass of the sample in grams	400	600	800
Change in Temperature	160° C	110° C	80° C

Elements of a Correct Response

Categories	Elements
Student correctly computes the change in temperature for each column	• 400g Graphite: 190-30 = 160 • 600g Graphite: 140-30 = 110 • 800g Graphite: 110-30 = 80

QUESTION 2

Using the data table you created, which of the following best describes the relationship between the mass of the sample and the change in temperature?

A. As the mass of the samples increased, the change in temperature of the samples increased.
B. As the mass of the samples increased, the change in temperature of the samples decreased.
C. As the mass of the samples increased, the change in temperature of the samples stayed the same.
D. As the mass of the samples increased, the change in temperature of the samples sometimes increased, and sometimes decreased

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LEARNING GOAL

Learning Performance

- Use a table to identify patterns in data.

Targeted DCIs, SEP, and CCC

- CC1-M.4 Graphs, charts, and images can be used to identify patterns in data.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	B. As the mass of the samples increased, the change in temperature of the samples decreased.

QUESTION 3

Which of the following best describes how the mass of a sample depends on the number of atoms and molecules that make up the sample?

A. The more mass the sample has, the more atoms and molecules make up the sample.

B. The more mass the sample has, the fewer atoms and molecules make up the sample.

C. How much mass a sample has doesn't affected by how many atoms and molecules make up the sample.

LEARNING GOAL

Learning Performance

- Identify the relationship between the mass of a sample of matter and the number of atoms and molecules that make up the sample.

Targeted DCIs, SEP, and CCC

- PS1.B-M.2: The total number of each type of atom is conserved, and thus the mass does not change.
- CC1-M.1: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. The more mass the sample has, the more atoms and molecules making up the material.

QUESTION 4

Which of the following best describes how the temperature of a sample depends on the speed of the atoms and molecules that make up the sample?

A. The faster the atoms and molecules that make up the sample are moving, the higher the temperature of the sample.

B. The slower the atoms and molecules that make up the sample are moving, the higher the temperature of the sample.

C. The temperature of a sample isn't affected by how fast the atoms and molecules that make up the sample are moving.

LEARNING GOAL

Learning Performance

- Identify the relationship between the temperature of a sample of matter and the speed of the atoms and molecules that make up the sample.

Targeted DCIs, SEP, and CCC

- PS3.A-M.5: 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.
- CC1-M.1: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. The faster the atoms and molecules that make up the sample are moving, the higher the temperature of the sample.

QUESTION 5

Using what you know about the relationships between energy, temperature, and the number and speed of the atoms and molecules that make up the graphite samples, explain why the three graphite samples had different changes in temperature even though they were heated by the same amount.

LEARNING GOAL

Learning Performance

- Explain trends in data, observed at the macroscopic scale, using energy concepts and relationships applied at the molecular scale.

Targeted DCIs, SEP, and CCC

- PS3.A-M.5: 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.
- PS3.A-M.3: The term "heat" as used in everyday language refers both to thermal energy (the motion of atoms or molecules within a substance) and the transfer of that thermal energy from one object to another. In science, heat is used only for this second meaning; it refers to the energy transferred due to the temperature difference between two objects.
- PS3.B-M.2: The amount of energy transfer needed to change the temperature of a matter sample by a given amount depends on the nature of the matter, the size of the sample, and the environment.
- SEP6-M.1: Construct an explanation that includes qualitative or quantitative relationships between variables that predict(s) and/or describe(s) phenomena.

- CC1-M.1: Macroscopic patterns are related to the nature of microscopic and atomic-level structure.

SCORING RUBRIC

Ideal Response

To increase the temperature of a sample of matter, energy must be transferred to it. The size of the increase in temperature depends on the mass of the sample. The more massive the sample, the smaller the increase in temperature. On the molecular scale, temperature is a measure of the average kinetic energy of the molecules that make up the sample and the mass of the sample is a measure of the number of molecules that make up the sample. If more molecules are present, more energy would need to be transferred to the sample to increase the kinetic energy of the molecules and raise the temperature the same amount.

Elements of a Correct Response

Categories	Elements

Student makes a correct claim	• The graphite samples had different changes in temperature because
	  ○ they have different masses/sizes
	  ○ they are made up of different numbers of atoms/molecules

Student states or uses a general science idea	• Temperature is a measure of the average kinetic energy or speed of particles of matter. [*links temperature and molecular kinetic energy/speed*] • The larger a sample is, the more energy is needed to change the temperature of a sample. [*links sample size and energy transfer*] • The size/mass of a sample is a measure of how many molecules make up the sample. [*links sample size and number of molecules*]
Student uses reasoning based on valid science ideas to explain the pattern	• More mass means more molecules, more molecules means more energy transfer needed to (increase the kinetic energy or speed of the molecules and) raise the temperature of the sample.

	Note: The student must include the word "energy" in their response to get this point, but mentioning kinetic energy is optional.

Sample Student Responses

Student response	Scoring description
"Because, the heat molecules would have spread out over the atoms and molecules."	Score = 0 The response does not include the idea that the samples have different masses, and it includes a misconception that the increase in temperature is caused by "heat molecules."
"The graphite samples were not the same mass, therefore when they were heated one got hotter than the others and none were the same."	Score = 1 The response only includes a claim about the samples having different masses but does not use any science ideas to support the claim.
"Due to a varying amount of atoms within each sample sample. A sample with a larger mass will have a longer time to heat up due to more atoms being in that sample, while vice versa happens for the ladder example."	Score = 2 The response includes a claim about the different amounts of atoms making up each sample and it links the claim to a science idea but does not use reasoning about energy explicitly.
"The three graphite samples had different changes in temperature even though they were heated by the same amount because they had different masses. The more mass something has, the more matter in it. This means that the number of atoms increases as the mass increased. Because they were all heated by the same amount, the graphite with the least mass had the highest	Score = 3 The response is a well-reasoned explanation that includes all the elements in the rubric.

temperature because the energy has to be disputed over less atoms, giving each atom more energy, and making them move faster. The faster the atoms move in something, the hotter it is. On the other hand, the energy giving to the biggest graphite same had to be spread out over more atoms, giving each atom less energy. The atoms and molecules would then move slower than in the smaller sample, making the change in temperature decrease."	

QUESTION 6

	Ceramic		
Mass of the samples in grams	400	600	800
Temperature **before** heating	20° C	20° C	20° C
Temperature **after** heating	210° C	150° C	120° C

Calculate the change in temperature for each ceramic sample by comparing its temperature before and after heating.

	Ceramic		
Mass of the sample in grams	400	600	800
Change in Temperature			

LEARNING GOAL

Learning Performance

- Use subtraction to determine the change in temperature of a material before and after being heated.

Targeted DCIs, SEP, and CCC

- SEP5-M.4: Apply mathematical concepts and/or processes (e.g., ratio, rate, percent, basic operations, simple algebra) to scientific and engineering questions and problems.

SCORING RUBRIC

Ideal Response

	Ceramic		
Mass of the sample in grams	400	600	800
Change in Temperature	190° C	130° C	100° C

Elements of a Correct Response

Categories	Elements
Student correctly computes the change in temperature for each column	• 400g Ceramic: 210-20 = 190 • 600g Ceramic: 150-20 = 130 • 800g Ceramic: 120-20 = 100

QUESTION 7

To better see the trends in the data, create a plot of the mass of the samples versus their change in temperature.

Your plot should include:

- Mass and temperature change data for both the graphite and ceramic samples
- A legend that labels the graphite and ceramic data

LEARNING GOAL

Learning Performance

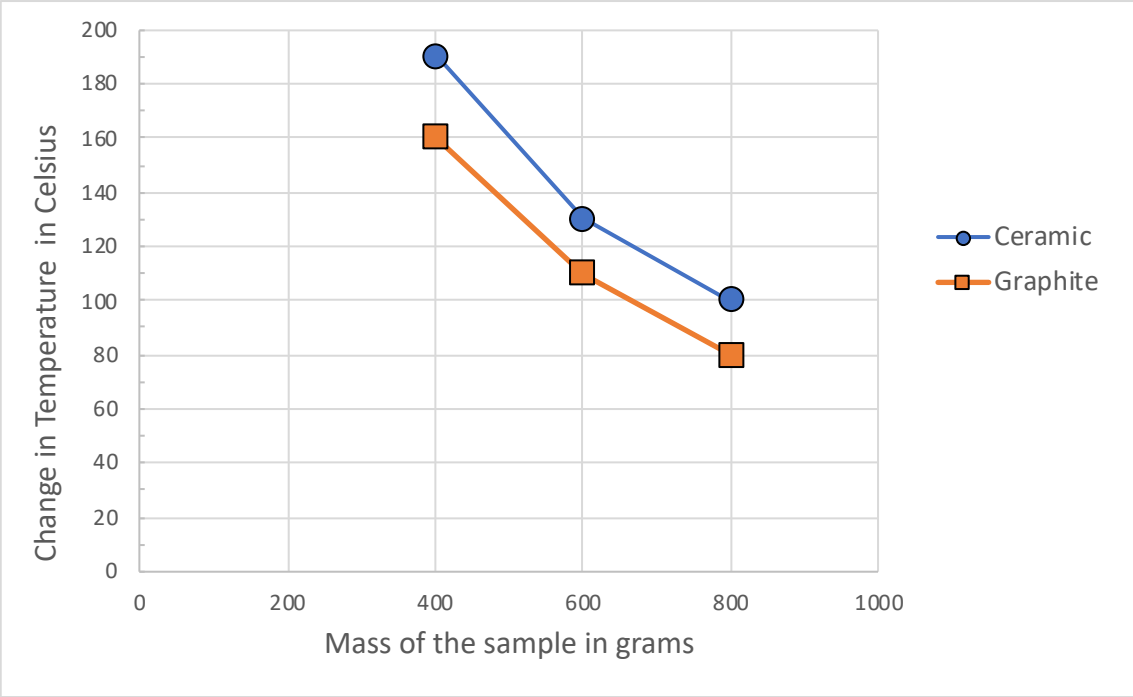
- Construct a graph from a table of data to visualize the relationship between mass and change in temperature.

Targeted DCIs, SEP, and CCC

- SEP4-M.1: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.

SCORING RUBRIC

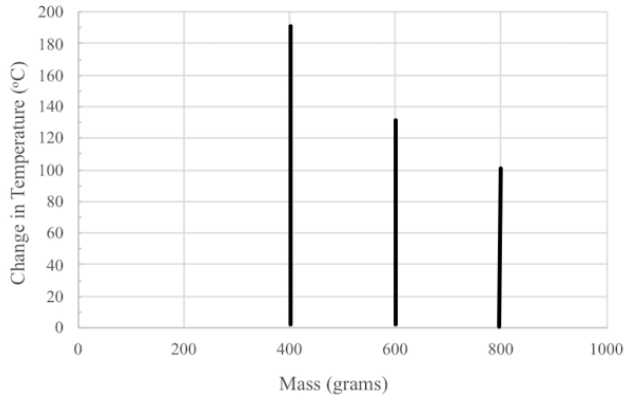
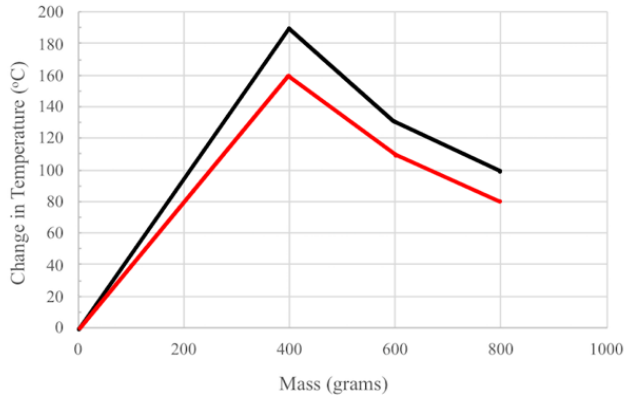
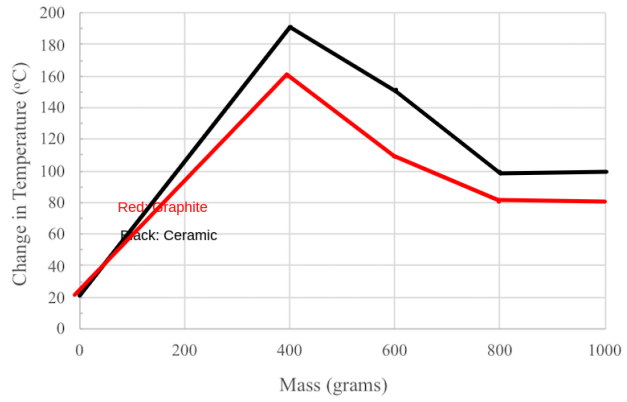
Ideal Response

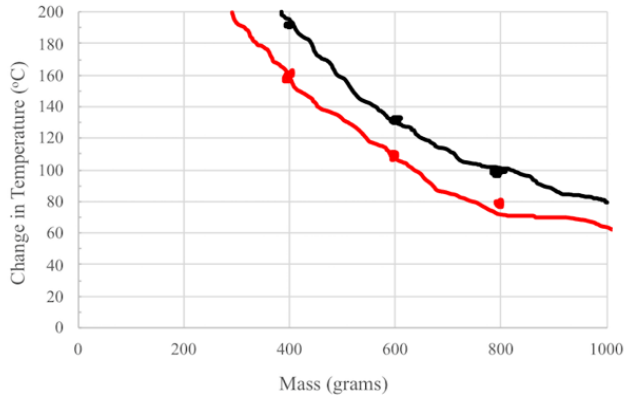
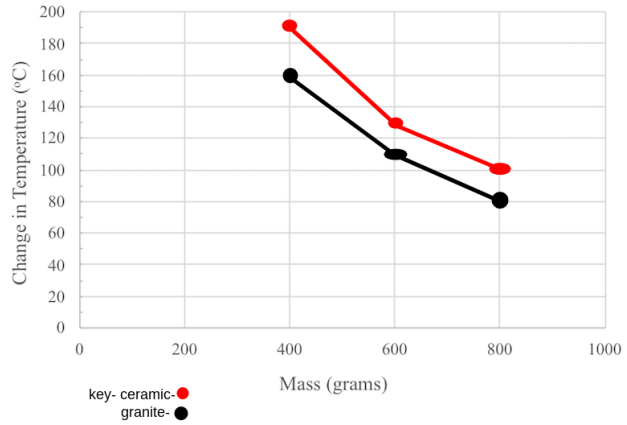


Elements of a Correct Response

Categories	Elements
Student graphs the correct data set and includes the requested components	• Graph includes data points for both ceramic and graphite • Graph includes indication of which data is for ceramic and which is for graphite
Student's graph includes the correct trends	• Graph shows that the change in temperature for both the ceramic and graphite decrease as mass increases • Graph shows that given the same mass the change in temperature for the ceramic is higher than the change in temperature of the graphite

Sample Student Responses

Student response	Scoring description
	Score = 0 The graph does not include data for both the graphite and ceramic samples.
	Score = 1 The graph includes two sets of data but no labels. It also does not include the correct trends.
	Score = 2 The graph includes the requested components, but does not include the correct trends.

	Score = 3 The graph includes the correct trends, but does not include a legend that identifies which data represents which material.
	Score = 4 The graph includes the requested components and the correct trends.

QUESTION 8

Using the change in temperature data and the plot you created, which of the following best describes how the ceramic and graphite data compare?

A. When comparing samples with the same mass, ceramic always had a larger change in temperature than graphite.

B. When comparing samples with the same mass, ceramic always had a smaller change in temperature than graphite.

C. When comparing samples with the same mass, ceramic always had the same change in temperature as graphite.

D. When comparing samples with the same mass, ceramic sometimes had a larger change in temperature than graphite, and ceramic sometimes had a smaller change in temperature than graphite.

LEARNING GOAL

Learning Performance

- Use a table and graph to identify patterns in data

Targeted DCIs, SEP, and CCC

- SEP4-M.1: Construct, analyze, and/or interpret graphical displays of data and/or large data sets to identify linear and nonlinear relationships.
- CC1-M.4: Graphs, charts, and images can be used to identify patterns in data.

SCORING RUBRIC

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. When comparing samples with the same mass, ceramic always had a larger change in temperature than graphite.

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