ASPECT

Assessing Students' Progress on the Energy Concept

Creating water droplets:

AP29-6 (MC) & AP30-6 (CR)

High School – Thermal Energy

TASK OVERVIEW

Students are introduced to a device that creates water droplets by condensing water vapor. The device is made up of hot and cold reservoirs of water separated by a section that contains air and water vapor. Students are shown a graph of temperature data for the reservoirs. They are asked to identify patterns in how the temperatures of the reservoirs change over time and then describe how energy is transferred between the reservoirs.

Students are then asked to predict what would happen if a heating element was added to the hot water reservoir. They construct a graph of how they think the temperature of the water in the cold reservoir will change if the temperature of the water in the hot reservoir is kept at 100 °C, and they are asked to predict whether the device would continue to produce water droplets under those new conditions.

TARGETED DCIs, SEPs, AND CCCs

Disciplinary core ideas

- 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-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

Science & engineering practices

- SEP7-H.4: Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
- SEP8-H.5: Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).
- SEP4-H.1: Analyze data using tools, technologies, and/or models (e.g., computational, mathematical) in order to make valid and reliable scientific claims or determine an optimal design solution.
- 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.

Crosscutting concepts

- CCC1-H.3: Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
- CCC2-M.2: Cause and effect relationships may be used to predict phenomena in natural or designed systems.

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

Identify and explain patterns in temperature data using the idea that energy transfers from higher temperature objects to lower temperature objects until equilibrium is reached. *Create a graph* predicting how the temperature of objects will change over time as they reach equilibrium. *Write an argument* using the idea that systems always evolve towards a stable state of equilibrium to predict whether a phenomenon will or will not continue to occur.

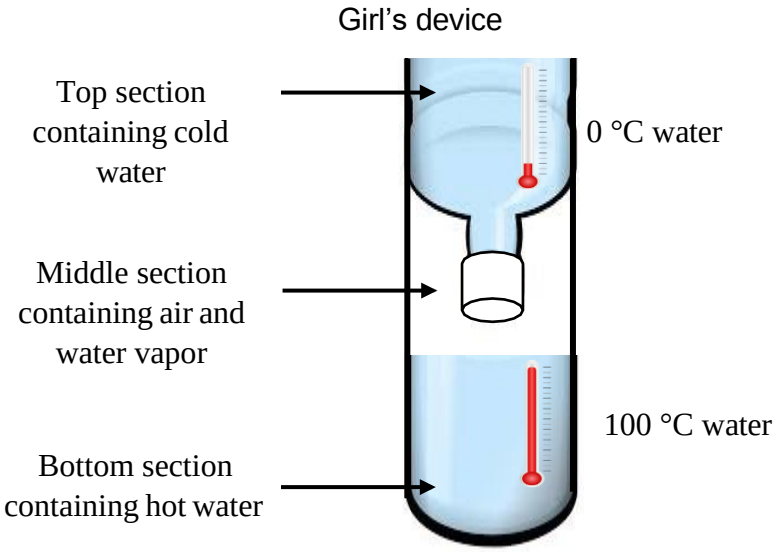
LINK TO ONLINE VERSION

http://assess.bscs.org/i/test/609

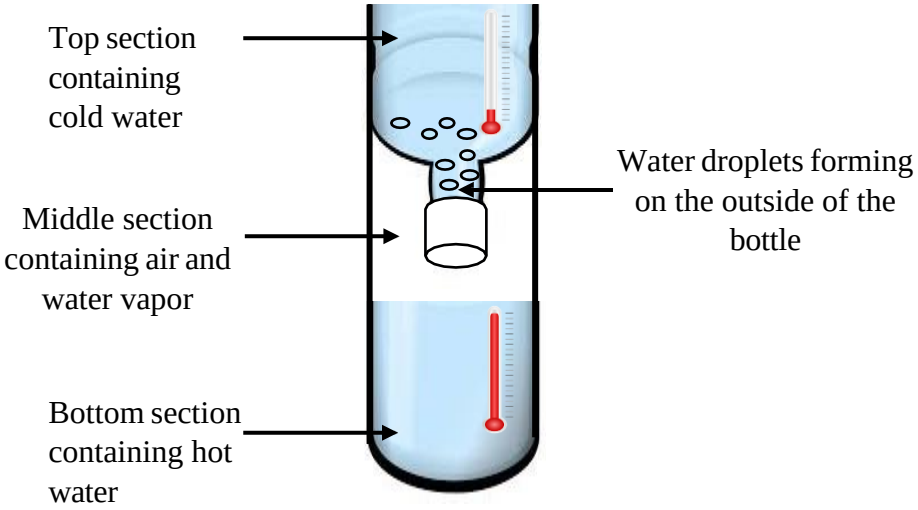
Task

As a science project, a girl builds a device to create water droplets. The device is made of a water bottle that has been cut into two sections. She takes the top section of the bottle and flips it over so that it sits inside the bottom section as shown below.

She places water at 0 °C in the top section and an equal amount of water at 100 °C in the bottom section. After placing the hot water in the bottom section, she leaves a space between the top and bottom sections. That middle section is empty except for air and water vapor. A diagram of the girl's device is shown below.

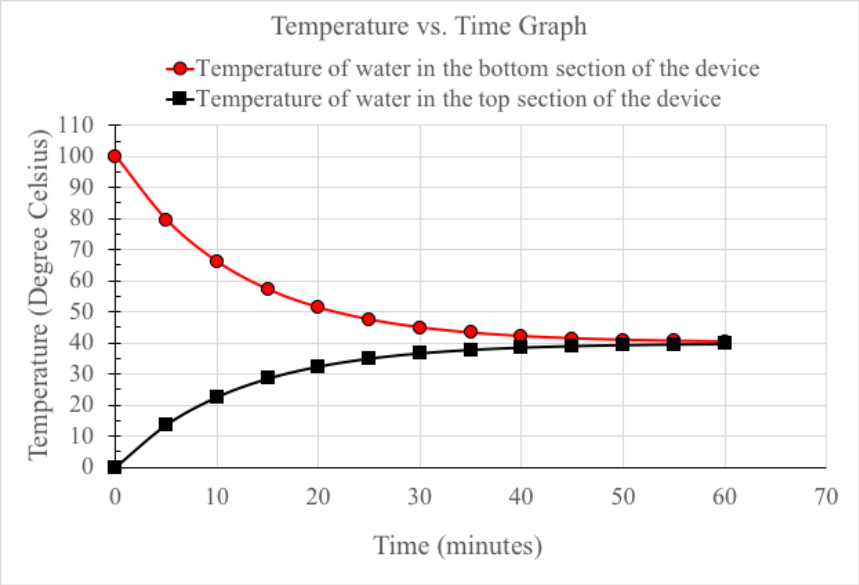


After a few minutes, water droplets form on the outside surface of the top section.



The girl notices that water droplets stop forming after an hour and eventually all the water droplets disappear.

The girl thinks that this is due to changes in the temperature of the water in each section. She refills the device with water at 0 °C and 100 °C, but this time she records the temperature of the water in each section every five minutes. Below is a plot of her data.



----------Constructed-response Version of #1----------

1. Describe the patterns you observe in the data for the temperature of water in the top and bottom sections of the device.

----------Multiple-choice Version of #1----------

1. Describe the patterns you observe in the data for the temperature of water in the top and bottom sections of the device.

    A. Over time the temperature in the top section increased while the temperature in the bottom section increased.

    B. Over time the temperature in the top section increased while the temperature in the bottom section decreased.

    C. Over time the temperature in the top section decreased while the temperature in the bottom section decreased.

    D. Over time the temperature in the top section decreased while the temperature in the bottom section increased.

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2. Which of the following best describes how energy was transferred during the experiment?

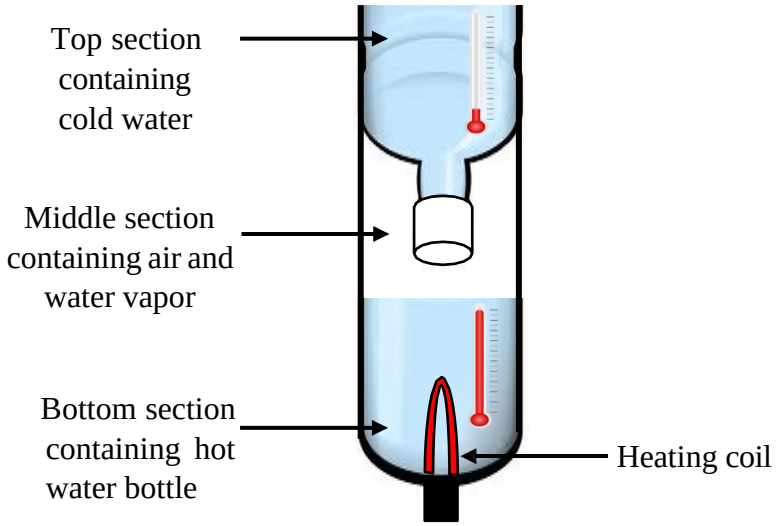
    A. Energy was transferred from the hotter water in the bottom section to the colder water in the top section until the energy was distributed evenly between the water in the top and bottom sections.

B. Energy was transferred from the hotter water in the bottom section to the colder water in the top section, but the energy never became evenly distributed between the water in the top and bottom sections.

C. Energy was transferred from the colder water in the top section to the hotter water in the bottom section until the energy was distributed evenly between the water in the top and bottom sections.

D. Energy was transferred from the colder water in the top section to the hotter water in the bottom section, but the energy never became evenly distributed between the water in the top and bottom sections.

The girl wants her device to continue to produce water droplets. So, she decides to add a heating coil that will heat the water in the bottom section of the device to keep its temperature at 100 °C.



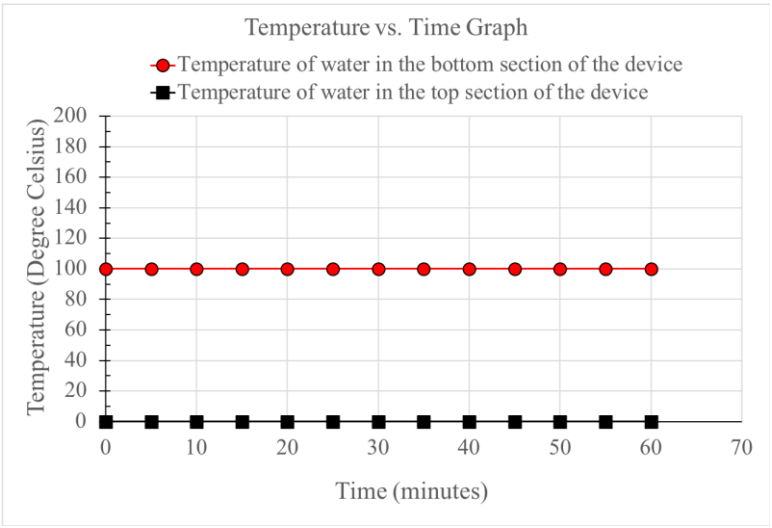
----------Constructed-response Version of #3----------

3. Draw a line on the graph representing how you think the temperature of the water in the top section of the device will change if the temperature of the water in the bottom section is kept at 100 °C.

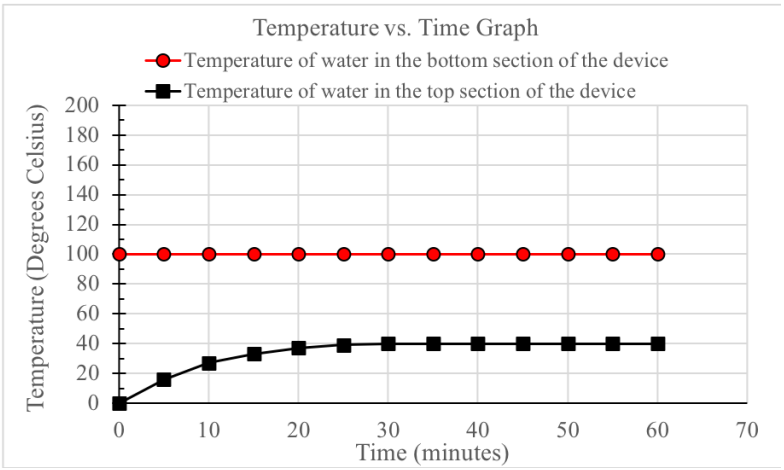
----------Multiple-choice Version of #3----------

3. Which of the following graphs best represents how you think the temperature of the water in the top section of the device will change if the temperature of the water in the bottom section is kept at 100 °C.?

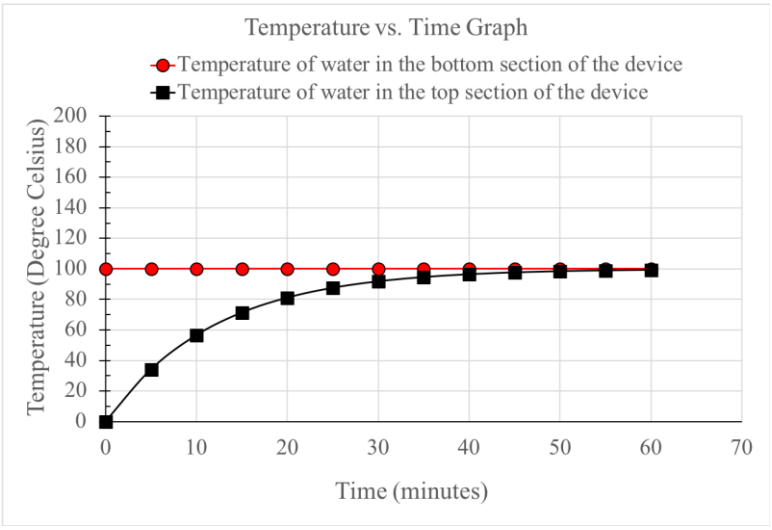
A.


Temperature vs. Time Graph
Temperature of water in the bottom section of the device
Temperature of water in the top section of the device
Temperature (Degree Celsius)
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Time (minutes)

B.


Temperature vs. Time Graph
Temperature of water in the bottom section of the device
Temperature of water in the top section of the device
Temperature (Degrees Celsius)
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Time (minutes)

C.


Temperature vs. Time Graph
Temperature of water in the bottom section of the device
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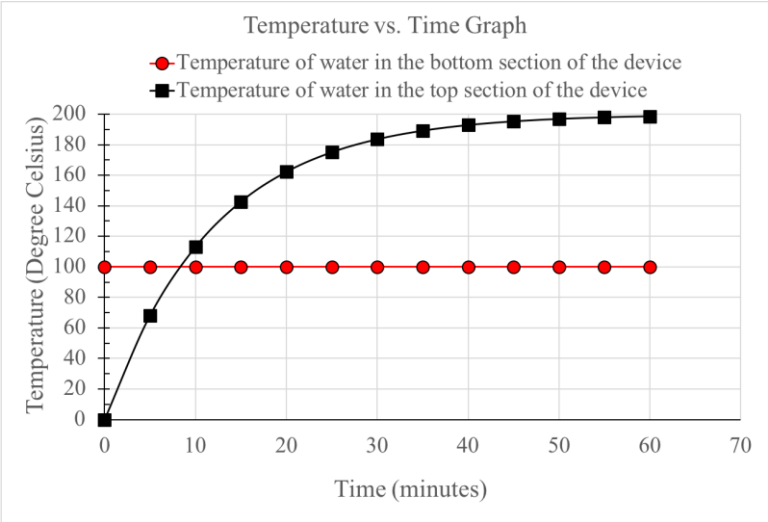
Temperature (Degree Celsius)
200
180
160
140
120
100
80
60
40
20
0
0
10
20
30
40
50
60
70
Time (minutes)

D.



4. The girl believes that keeping the water in the bottom section of the device at 100 °C will cause the device to continue to produce water droplets in the middle section.

   Write an argument for or against the idea that the device will continue to produce water droplets as long as the heater is on and the the water in the bottom section is kept at 100 °C. Support your argument using the graph you [selected/created], evidence from the girl's previous experiments, and what you know about energy transfer. Clearly state any assumptions you are making in your argument.

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

QUESTION 1

Describe the patterns you observe in the data for the temperature of water in the top and bottom sections of the device.

LEARNING GOAL

Learning Performance

- Analyze a graph to describe patterns in temperature data.

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.
- CC1-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 water in the top section decreases while the temperature of the water in the bottom section increases. Eventually, the water in both sections of water have the same temperature (40 ºC).

Elements of a Correct Response

Categories	Elements
Student describes the following patterns in the graphed data	• The temperature of the water in the bottom section of the device decreased over time. • The temperature of the water in the top section of the device increased over time • Eventually, the water in the bottom and top sections reach the same temperature. <u>Note</u>: Describing the temperature changes as the temperatures converging or coming together/to equilibrium is acceptable for all three bullets.
OR	
Student selects the correct multiple-choice answer	D. Over time the temperature in the top section decreased while the temperature in the bottom section increased.

Sample Student Responses

Student response	Scoring description
"The water starts to decrease and then stays still"	Score = 0 The student does not clearly describe the patterns in the data.
"After 1 hour both temperatures are the same."	Score = 1 The response includes the observation that after 1 hour the temperatures will be the same, but it does not describe how the temperatures of the sections changes over time.
"I observed that as the top section is heating up, the bottom section is cooling off at the same rate."	Score = 2 The response describes the patterns at the beginning of the time period but does not include the observation that the temperatures end up being the same.
"The top part goes up in temperature and the bottom goes down and they meet at 55."	Score = 3 The response describes all the patterns in the data. No point was deducted for referencing 55 °C instead of 40 °C.

QUESTION 2

Which of the following best describes how energy was transferred during the experiment?

A. Energy was transferred from the hotter water in the bottom section to the colder water in the top section until the energy was distributed evenly between the water in the top and bottom sections.

B. Energy was transferred from the hotter water in the bottom section to the colder water in the top section, but the energy never became evenly distributed between the water in the top and bottom sections.

C. Energy was transferred from the colder water in the top section to the hotter water in the bottom section until the energy was distributed evenly between the water in the top and bottom sections.

D. Energy was transferred from the colder water in the top section to the hotter water in the bottom section, but the energy never became evenly distributed between the water in the top and bottom sections.

LEARNING GOAL

Learning Performance

- Describe how energy is transferred from the hotter section to the colder section until energy is evenly distributed.

Targeted DCIs, SEP, and CCC

- 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-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.

Elements of a Correct Response

Categories	Elements
Student selects the correct multiple-choice answer	A. Energy was transferred from the hotter water in the bottom section to the colder water in the top section until energy was distributed evenly between the water in the top and bottom sections.

QUESTION 3

Draw a line on the graph representing how you think the temperature of the water in the top section of the device will change if the temperature of the water in the bottom section is kept at 100 °C.

LEARNING GOAL

Learning Performance

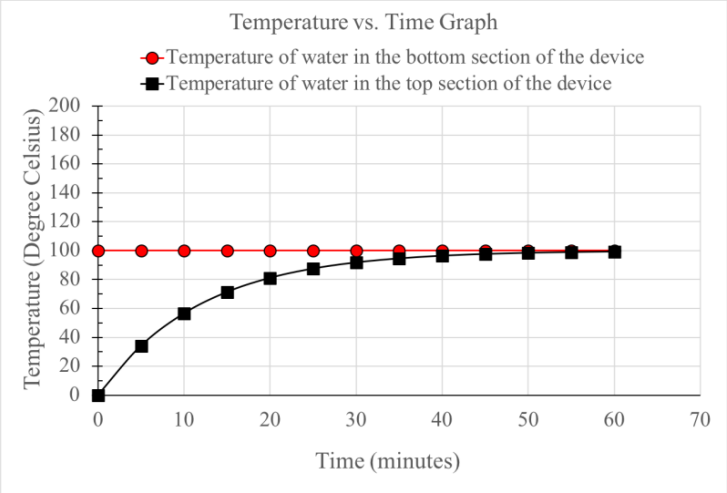
- Draw a graph representing how the temperature of water changes as energy is transferred to it.

Targeted DCIs, SEP, and CCC

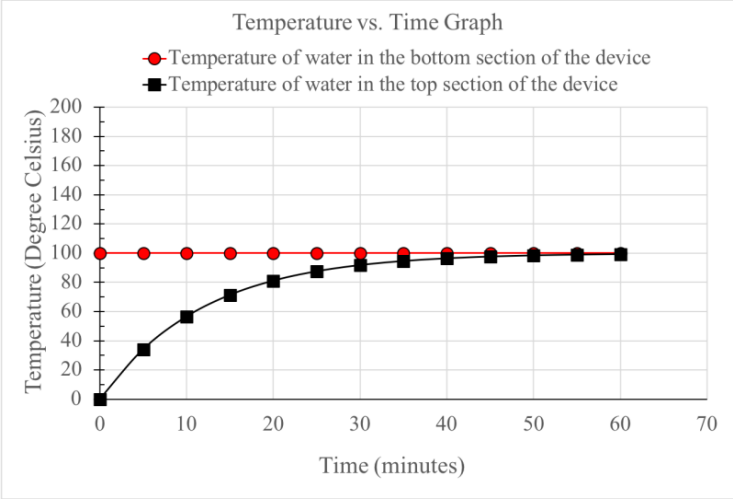
- PS3.B-H.5: Uncontrolled systems always evolve toward more stable states--that is, toward more uniform energy distribution (e.g., water flows downhill, objects hotter than their surrounding environment cool down).
- SEP8-H.5: Communicate scientific and/or technical information or ideas (e.g. about phenomena and/or the process of development and the design and performance of a proposed process or system) in multiple formats (i.e., orally, graphically, textually, mathematically).
- CC1-H.3: Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.

SCORING RUBRIC

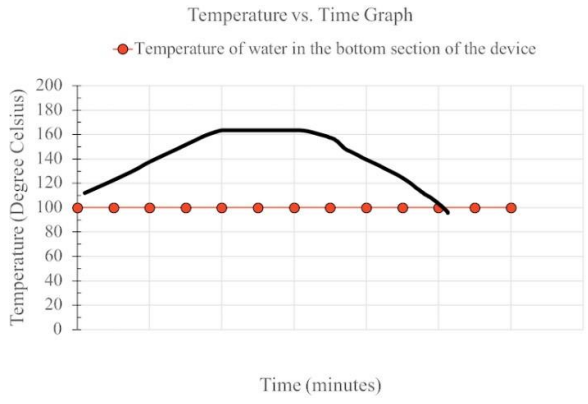
Ideal Response

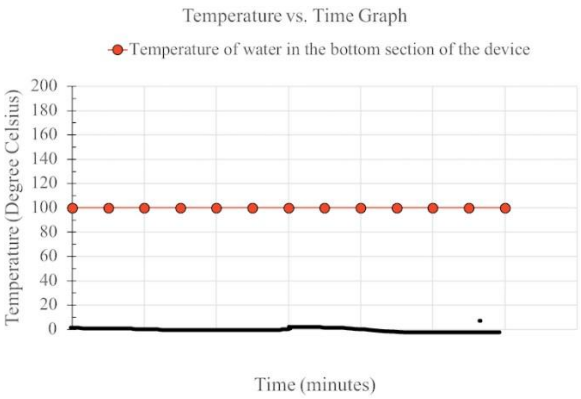
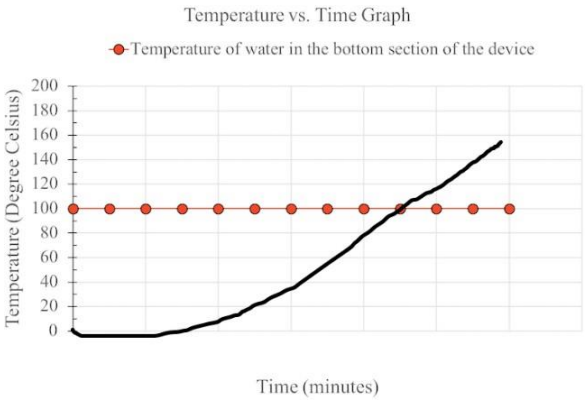
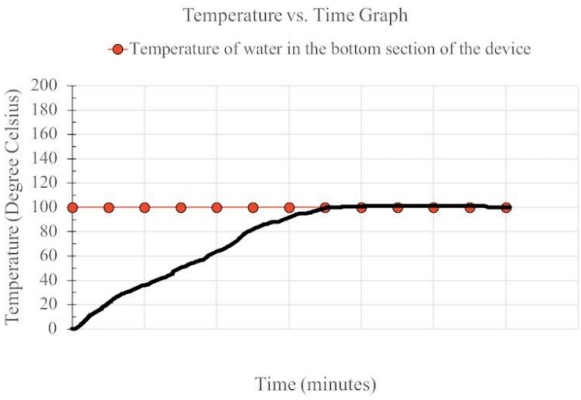


Elements of a Correct Response

Categories	Elements
Student's graph includes the following elements	• Temperature of the top section starts at 0 °C • Temperature of the top section increases over time • Temperature of the top section of water equilibrates to 100 °C
OR	
Student selects the correct multiple-choice answer	C. 

Sample Student Responses

Student response	Scoring description
	Score = 0 The response does not include a line that starts at 0 °C as described in the scenario nor does it correctly represent how the temperature would change over time.

	Score = 1 The response includes a line that starts at 0 °C but it does not correctly represent how the temperature would increase over time and equilibrate to 100 °C.
	Score = 2 The response includes a line that starts at 0 °C and increases over time, but it does not represent how the temperature would equilibrate to 100 °C.
	Score = 3 The response includes all the elements of the rubric.

QUESTION 4

The girl believes that keeping the water in the bottom section of the device at 100 °C will cause the device to continue to produce water droplets in the middle section.

Write an argument for or against the idea that the device will continue to produce water droplets as long as the heater is on and the water in the bottom section is kept at 100 °C. Support your argument using the graph you created, evidence from the girl's previous experiments, and what you know about energy transfer. Clearly state any assumptions you are making in your argument.

LEARNING GOAL

Learning Performance

- Write an argument for or against the idea that the system will reach thermal equilibrium.

Targeted DCIs, SEP, and CCC

- 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-M.3: Energy is spontaneously transferred out of hotter regions or objects and into colder ones.
- SEP7-H.4: Construct, use, and/or present an oral and written argument or counter-arguments based on data and evidence.
- CCC1-H.3: Patterns of performance of designed systems can be analyzed and interpreted to reengineer and improve the system.
- CCC2.M2: Cause and effect relationships may be used to predict phenomena in natural or designed systems.

SCORING RUBRIC

Ideal Response

Eventually the device will stop producing water droplets because the top and bottom section of water will be at the same temperature. Energy will be transferred from the hotter bottom section to the cooler top section until both sections are at 100 °C. As this occurs, fewer droplets will be produced. Once both regions are at 100 °C no

droplets will be produced because the energy transfer will stop at which point the device will be in a new stable equilibrium.

Elements of a Correct Response

Categories	Elements
Student makes the correct prediction.	• The revised design will eventually stop producing water droplets.
Student cites evidence and/or uses their graph to support their argument	• The graph shows that the temperature of the water in the top section will gradually increase until it reaches 100 °C. [Note: Student must mention the graph to get this point.] • The previous experiment showed that the droplets will stop forming once the temperature of the water in the sections becomes equal.
Student either states or uses a general science idea	• Energy is spontaneously transferred out of hotter regions or objects and into colder ones (i.e., energy will be transferred from the hotter bottom section to the cooler top section). [*Conduction*] [Note: Student must use the word energy to get this point.] • When a warmer object is touching a cooler object, the warmer object gets cooler and the cooler object gets warmer until they are at the same temperature at which point the temperature won't change anymore (i.e., the temperature of the top section will increase until the temperature of the water in the sections reach equilibrium). [*thermal equilibrium*] • Uncontrolled systems always evolve towards more stable states-that is, towards more uniform energy distributions within the system (i.e., energy will be transferred from the bottom section to the top section until the energy is equally distributed between the sections). [*uniform energy distribution*]
Students supports their prediction with reasoning that links the evidence and science ideas	• The difference in temperature was causing the water droplets to form, so if there is no temperature difference, water droplets will no longer form. OR

	• The transfer of energy from the bottom section to the top section was causing the water droplets to form, so if there is no energy transfer, water droplets will no longer form.
Student uses productive ideas not represented above	• Student references the effect the ambient temperature will have on the temperature of the water in the device.

Sample Student Responses

Student response	Scoring description
"This device with continue to produce water droplets as long as the heater is on or it is above hot water."	Score = 0 The response includes an incorrect prediction.
"I believe that keeping the water int he bottom part at 100 will not cause the device to keep producing the water droplets"	Score = 1 The response includes a correct claim, but the claim is not supported by evidence and energy ideas.
"For a while it will produce water droplets and might even make more droplets for a longer time then before but eventually the heat will be spread out evenly till the top water is also 100 C then the droplets."	Score = 2 The response correctly predicts that the device will stop making droplets and supports the prediction with energy ideas but does not include evidence or reasoning that links the evidence to the science ideas.
"This is incorrect because eventually the energy from the bottom section of the water will transfer to the top section causing the top section to rise in temperature. They will become the same temperature and then water droplets will not be produced because there is no difference in temperature."	Score = 3 The response includes a well-reasoned argument for why the heater will not continue to produce more droplets, but it does not cite any evidence.

“The heater will not help to produce more water droplets, as the water droplets appear to be formed by a large difference in temperature between the two sections. If the bottom section continues to be heated, but the top section is not continually cooled, then eventually, as seen on the graph, the top section will match the temperature of the bottom section. In the first graph, the temperatures of both sections are equal, which is when the water droplets stopped, so if the same happens with the top and bottom sections with the heater, then the heater will not help to produce more water droplets.”	Score = 4 The response includes a well-reasoned argument for why the heater will not continue to produce more droplets.

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