Name: __________________________________

**Answer Key: Simulation: Understanding Specific Heat**

**Background**
In this simulation, you will take on the role of an engineer building a new home. One of the decisions you have to make is what materials you will use to build the house so that it is energy efficient without being too expensive. One factor that affects energy efficiency is **specific heat capacity**.

1. Imagine being barefoot outside on a hot summer’s day in a sunny place – would you rather be standing on concrete or grass? Why?
   I would rather stand on the grass because it would feel much cooler on my feet. Concrete gets very hot in the sun and could burn my feet.

2. You put two pots of water on the stove to boil. Both pots are the same size and are on the same size burner at the same heat setting, and one pot has twice as much water as the other. Which one will boil faster? Why do you think that is?
   The pot with less water will boil faster. There’s not as much water to heat up, so the same amount of energy from the stove will be distributed over a smaller amount of water, causing it to heat up and reach its boiling point sooner.

3. You have the same pots from question two, but this time they have the same amount of water and one burner is set to high, the other to low. Which one will boil faster? Why do you think that is?
   The pot on the high burner will boil faster. Since both pots have the same amount of water, the one that receives more energy at a time (higher burner setting) will increase in temperature more rapidly than the one that receives less energy at a time (lower burner setting).

**Procedure**
Answer the following questions as you go through the simulation found at: [https://teachchemistry.org/specific-heat](https://teachchemistry.org/specific-heat).

1. In your own words, define **specific heat capacity**.
   *Answers may vary slightly.* Specific heat capacity describes the relationship between the energy added to/removed from a material, the mass of the material, and the resulting temperature change. Technical definition: The amount of energy required to raise the temperature of 1 g of a material by 1°C. That means that a substance with a higher specific requires more energy to raise that material’s temperature by the same amount compared to something with a lower specific heat.

2. In the example comparing Substance A and Substance B, which one has a higher specific heat capacity? Explain.
   Substance B has a higher specific heat capacity – if the same amount of energy is applied to both materials, but the temperature increases less for B, that means it would need *more* energy to reach the same temperature as A. If it requires more energy to heat it to the same temperature, it has a higher specific heat capacity.
3. Show your work in the space below for the specific heats you calculated for the four materials in the simulation. Be sure to include units and round your answers to the correct number of significant figures. Check your answers with the simulation.

**Version 1**

| Material 1: Vibranium          | 2000 J / (50 g)(46.9°C - 20.0°C) = 2000 J / (50 g)(26.9°C) ≈ 1.5 J/g°C |
| Material 2: Beskar            | 2000 J / (50 g)(38.4°C - 20.0°C) = 2000 J / (50 g)(18.4°C) ≈ 2.2 J/g°C |
| Material 3: Blanchettium      | 2000 J / (50 g)(43.7°C - 20.0°C) = 2000 J / (50 g)(23.7°C) ≈ 1.7 J/g°C |
| Material 4: Gundarium         | 2000 J / (50 g)(35.3°C - 20.0°C) = 2000 J / (50 g)(15.3°C) ≈ 2.6 J/g°C |

**Version 2**

| Material 1: Bolanium          | 1000 J / (100 g)(24.8°C - 20.0°C) = 1000 J / (100 g)(4.8°C) ≈ 2.1 J/g°C |
| Material 2: Adamant           | 1000 J / (100 g)(25.5°C - 20.0°C) = 1000 J / (100 g)(5.5°C) ≈ 1.8 J/g°C |
| Material 3: Finkonium         | 1000 J / (100 g)(27.7°C - 20.0°C) = 1000 J / (100 g)(7.7°C) ≈ 1.3 J/g°C |
| Material 4: Cavorite          | 1000 J / (100 g)(26.3°C - 20.0°C) = 1000 J / (100 g)(6.3°C) ≈ 1.6 J/g°C |

4. Which of the four materials meet the minimum specific heat capacity criteria of at least 1.8 J/g°C?
   - **Version 1:** Beskar and Gundarium
   - **Version 2:** Bolanium and Adamant

5. Show your work in the space below for your calculations of the total cost of those two materials. **Total Cost = Material cost + (Labor Cost)(Time)**

   **Version 1:**
   - **Beskar:** Total = $6,000 + ($100/hr)(4 hr) = $6,000 + $400 = $6,400
   - **Gundarium:** Total = $5,000 + ($150/hr)(12 hr) = $5,000 + $1,800 = $6,800

   **Version 2:**
   - **Bolanium:** Total = $4,000 + ($150/hr)(8 hr) = $4,000 + $1,200 = $6,200
   - **Adamant:** Total = $5,000 + ($100/hr)(6 hr) = $5,000 + $600 = $5,600

6. What material did you choose for your building project and why?
   - **Version 1:** Beskar, because it costs $400 less than Gundarium, even though both meet the minimum specific heat capacity requirement.
   - **Version 2:** Adamant, because it costs $600 less than Bolanium, even though both meet the minimum specific heat capacity requirement.

**Analysis**

1. The scenarios presented in the background questions at the beginning of this activity each resulted in different temperature changes (ΔT) because of the manipulation of one of the other variables in the specific heat capacity equation (Q, m, or c). Which variable was changed in each question? Explain.

   - **Question 1:** c – specific heat capacity changes with the type of material
   - **Question 2:** m – the mass of the water being heated was different
   - **Question 3:** Q – the amount of heat energy changed with the burners at different settings
2. In this simulation, you solved for the specific heat capacity of several materials, but the specific heat for many materials is known. Use the specific heat equation and related variables to solve the following problems:
   a. A potted plant is placed under a grow lamp, which provides 4,200 J of energy to the plant and the soil over the course of an hour. The specific heat capacity of the soil is about 0.84 J/g°C and there are about 2,400 g of soil. How much does the temperature of the soil increase?
   \[ \Delta T = \frac{Q}{mc} = \frac{4200 \text{ J}}{(2400 \text{ g})(0.84 \text{ J/g°C})} \approx 2.1°C \]
   b. Water has a specific heat of 4.184 J/g°C. If the temperature of 250 g of water changes from 22.9°C to 14.7°C, how much heat energy was removed from the water?
   \[ Q = mc\Delta T = (250 \text{ g})(4.184 \text{ J/g°C})(14.7°C - 22.9°C) = (750 \text{ g})(4.184 \text{ J/g°C})(-8.2°C) \approx -8600 \text{ J} \]
   (Note that Q is negative because \( \Delta T \) is negative and the water loses energy.)
   c. A sample of aluminum (\( c = 0.900 \text{ J/g°C} \)) is heated from 20.8°C to 38.7°C using 3,750 J of energy. What is the mass of the aluminum sample?
   \[ m = \frac{Q}{c\Delta T} = \frac{3750 \text{ J}}{(0.900 \text{ J/g°C})(38.7°C - 20.8°C)} = \frac{3750 \text{ J}}{(0.900 \text{ J/g°C})(17.9°C)} \approx 233 \text{ g} \]
   d. Determine the final temperature of sample with a specific heat of 1.1 J/g°C and a mass of 385 g if it starts out at a temperature of 19.5°C and 885 J of energy are added to it.
   \[ \Delta T = \frac{Q}{mc} = \frac{885 \text{ J}}{(385 \text{ g})(1.1 \text{ J/g°C})} \approx 2.1°C \]
   The temperature increases by 2.1°C, and since it starts at 19.5°C, the final temperature would be \( 21.6°C \).

3. In this simulation, we only addressed two factors – energy efficiency (as measured by specific heat capacity) and cost – when determining what building materials to use. In real life, you would have to consider other factors as well. List at least 2 additional factors that might impact material choice for a home building project. 
   Answers will vary. Possible answers include: Appearance/aesthetics, durability/lifetime of materials before needing repair or replacement, cost of repair or replacement, environmental impact of producing those materials, what the customer values more (ex: low cost is more important than appearance vs. appearance is more important than cost), local regulations/HOA requirements

4. Substance X has a specific heat capacity that is twice as large as Substance Y. If both samples ended up at the same change in temperature from the same amount of energy added, what is the relationship between the masses of the two samples? Explain.
   If both substance have the same change in temperature with the same amount of energy, but they have different specific heat capacities, their masses must compensate for the difference in specific heat capacities. Since Substance X has twice as high a specific heat capacity, it will take more energy to heat to a certain temperature than Substance Y. Therefore, the mass of the sample of Substance X must be twice as much as that of Substance X to absorb the same amount of energy and end at the same temperature.
5. Using what you’ve learned about specific heat capacity, propose an explanation for why the sand at the beach can feel so hot when the water feels much cooler even though they both receive the same amount of energy from the sun. Sand must have a much lower specific heat capacity than water. It requires less energy to increase the temperature, so when the energy from the sun warms both the sand and the water, the sand reaches a higher final temperature than the water. Students might also say something about how the deeper water is cooler and as the warmer surface water mixes with the cooler deeper water it will slow the heating process. The layers of sand don’t mix quite as much, and students might also note that sand that is under the surface and not exposed to the sun is much cooler than the surface sand. The water, as a liquid, mixes more freely and so the effective mass being heated is greater.

Extension
Using your knowledge of specific heat capacity, temperature, mass, and energy, design an experiment to determine the average energy output per minute of a stove burner at its highest setting. (Note: the specific heat capacity of many common materials are well established and can be found in chemistry textbooks and other reputable sources!) Be sure to include a list of materials and procedures that could be followed by another scientist.

Answers will vary. One possible scenario involves boiling a certain mass of water (c = 4.184 J/g°C) and measuring the temperature change over a certain period of time. Another substance could be used, but water would be safe and easy.

Materials:
- Small pot
- Balance or measuring cup (1 g water = 1 mL water at room temperature)
- Water
- Stove
- Oven gloves
- Thermometer
- Stop watch or clock/watch

Procedure:
1. Measure out 500 g (500 mL) of water and put it in a pot. Set it aside.
2. Turn on a stove burner to high and allow it to heat up for a few minutes so its energy output will be consistent.
3. Record the initial temperature of the water in the pot.
4. Put the pot on the hot stove burner.
5. Record the temperature after 10 minutes.
6. Calculate Q using \( Q = mc\Delta T \) and the data you recorded. (For water, \( c = 4.184 \text{ J/g}^\circ\text{C} \))
7. Divide that by 10 minutes to get the average energy output per minute.
8. Repeat steps 1-7 with different masses of water to see if you get consistent results.

If you want to break it down, further you could measure the temperature every minute for 10 minutes and see if there is a consistent energy output as the water is heated.