Names and picture:

____

b) Now, rescale your temperature graph so that the temperature range is about 1°C. For example, if you measured a temperature of 23.9°C, try scaling the graph to go from 23.5°C to 24.5°C°. Then try scaling it to an even smaller ranger say 0.5°C or 0.2°C. Comment on what you observe.

c) Based on your observations in part b), how much can you trust your temperature reading? Is it precise to within 1°C? To within 0.5°C? To within 0.1°C? Explain your reasoning.

As demonstrated in the previous activity, your temperature measurements will not be perfectly accurate. There will be some (we hope small) amount of uncertainty associated with any measurement process and it is wise to always keep this in mind. Knowing how much uncertainty is inherent in your measurements will help you determine when two measurements are the same. For example, if your temperature sensor is precise to within 0.5°C, and you measure the temperature of two cups of water to be T_1=22.3°C and T_2=23.6°C, you can be pretty sure that these temperatures are, in fact, different. If, on the other hand, you measure these temperatures to be, T_1=22.3°C and T_2=22.9°C, you cannot know for sure whether or not these two temperatures are different because they could each be wrong by as much as 0.5°C.

Most electronic temperature sensors are precise to within 0.5°C and many are precise to within 0.1°C (or even better). In this unit, we will not be interested in measuring temperature differences that are smaller than 1°C.

1.2 MIXING WATER

The next two activities constitute a game. The object of the game is to be able to predict the final temperature when two cups of water (initially at different temperatures) are mixed together. As you might guess, this is fairly easy if the two cups have the same amount of water, but it is not so easy when they don't. Before beginning an experiment it is useful to make a prediction about what you expect to see. It is important to make the prediction as specific as possible. For example, in the next activity you will predict the final temperature that results from mixing together a cup of hot water and a cup of cold water. You might predict that the final temperature will be somewhere in between the two starting temperatures, and you'd be correct. But a better prediction will be more specific about the final temperature. Will the final temperature be exactly halfway between the two temperatures? One third of the way?

Developing such a prediction involves considering what factors are likely to affect the experiment (e.g., the amount of water) and what factor are unlikely to affect the experiment (e.g., day of the week). Then the experiment tests your hypothesis. If the results of the experiment are inconsistent with your hypothesis, you know that it is false. On the other hand, if your experimental results are consistent with your hypothesis, your hypothesis is supported. It is important to remember that a hypothesis can never be proven correct. Even though a hypothesis may be supported by many observations and experiments, only one careful experiment is required to show that it is incomplete or incorrect it.

Activity 1.2.1 Final Temperature—Predictions

a) Suppose you mix two cups of water that are at different temperatures, one at a high temperature, T_H, and one at a lower temperature, T_C. What do you think the final temperature of the mixture will be? (i.e., will it be higher than T_H, lower than T_C, right in the middle, or something else?) Explain briefly

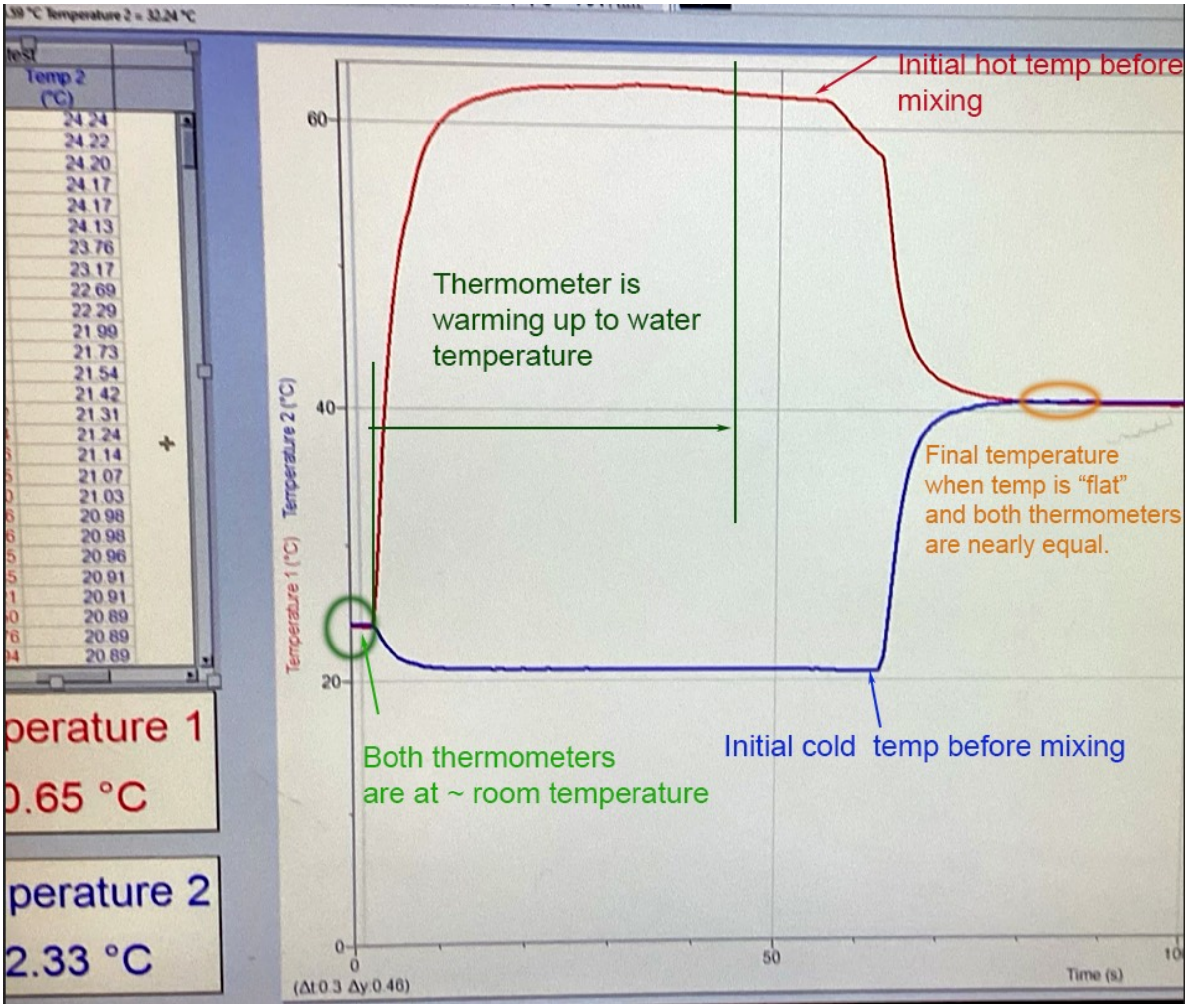
b) What factors do you think will influence the final temperature of the mixture? Explain.

c) To make your ideas a bit more concrete, predict the final temperature of a mixture of 50 grams of water[1] at 60ºC mixed with 100 grams of water at 20ºC. Try to explain the reasoning behind your prediction as best you can. **Note:** If you have to make a bit of a guess at this point, that's fine.

Testing Your Predictions

In this next activity you'll have a chance to test the predictions you just made. Remember that the goal is to come up with a method of predicting the final temperature when two *arbitrary* amounts of water at different temperatures are mixed together. So be prepared to make a number of different measurements.

[1] A gram is measurement of *mass*, which is a measure of "how much stuff" you have. One milliliter (ml) of water has a mass of 1 gram (gm)



A typical experiment is above. When recording started both thermometers were at room temperature.

Once a thermometer is placed in the water, it takes a while for the thermometer itself to warm up (or cool down) to the temperature of the water. So you should wait until the temperature is not changing much.

This graph even shows that the hot water thermometer temperature went up, and then started going gradually down. This probably reflects the actual temperature of the water, as the hot water cools down.

The “initial temperatures” of the hot and cold water cups are actually the *last* temperature before you pull out the thermometers, and pour the hot water into the cold water.

After you put both thermometers into the combined-water cup, they again each take a little time to reach the temperature of the water. Wait till the temp of both thermometers are “flat” (not changing) again to decide what the temperature of the water mixture is.

Activity 1.2.2 Final Temperature—Observations

When the instructions say "print out…your data" you may instead take a picture of your graph of temperature vs time.

Add an empty page to your notability file as needed to include a large, easy-to-read picture of your graph.

a) Typically, when beginning a scientific investigation, it is best to start simple. Therefore, you should begin by mixing together two cups of *equal* amounts of water (say, 50 or 100 grams each) that are at different temperatures. It might be difficult to get specific temperatures, so just use hot tap water and cool tap water. To record your observations, place an electronic temperature sensor in each cup and begin recording data. Then, after waiting until the sensors are recording a fairly steady value, pour the cold water into the cup with the hot water and place both temperature sensors in the final mixture. Print out a copy of your data to include in your activity guide. Is the final temperature halfway between the two initial temperatures?

Confirm that the final temperature is close to halfway between the two initial temperatures before going on.

b) You should have noticed that both temperature sensors end up at the same final temperature (within a few tenths of a degree Celsius). If they differ from each other by more than 0.5°C, ask your instructor how to calibrate your sensors. You should also have noticed that the final temperature was not exactly halfway between the two initial temperatures. Most often, the final temperature will be a bit below the halfway point (usually less than 1°C). Explain why this happens. **Hint:** What happens to the temperature of a cup of hat water that sits in a room for a long time?

c) The fact that the final temperature was (probably) not exactly halfway between the two initial temperatures is worth thinking about briefly. There could be some outside influence that affects the experiments (as alluded to above), or there could be other measurement errors that lead to the unexpected result. Besides temperature measurements, what other measurements did you make in this experiment? How might errors in these measurements lead to a different final temperature than you expected?

d) Now try the same experiment again, except, this time, combine 100 grams of cold water and only 50 grams of hot water. Again, write down the initial and final temperature and print out a copy of your graph to include in your activity guide. **Note:** Remember to pour the cold water into the cup of hot water.

e) Using the data from this experiment, work with your group to determine an equation that allows you to calculate the final temperature you measured above. **Hint:** What fraction of the total mixture was initial in the cold water cup and what fraction was initially in the hot water cup? Do these fractions have any bearing on where the final temperature will lie between the two initial temperatures? Remember that your final temperature measurement might be a little lower than expected.

f) When you have an equation that works, generalize it so that it is valid for arbitrary amounts of water and arbitrary initial temperatures. Show your work and write your new equation below.

g) Using your newfound equation calculate the final temperature when mixing 50 grams of water at 60°C and 100 grams of water at 20°C. Do you results agree with your predictions from Activity 1.2.1? (It's okay if they don't)

h) Try one more experiment with 100 grams of cold water and 25 grams of hot water. Compare your experimental measurements with your theoretical predictions. They should be quite close!

Congratulations! You have successfully developed a method for predicting the final temperature when mixing two cups of water together. This kind of quantitative reasoning plays an important part in the scientific process. It is equally important to consider sources of error and outside influences that may have affected your experiment. Each measurement that is made is a potential source of error so that making careful measurements is essential. Furthermore, even if perfect measurements could be made, outside influences (such as the cooling of the hot water) can also have an impact on the final results of an experiment. Often it is only possible to understand a particular result after including the outside influences and sources of error.

Checkpoint Discussion: Before proceeding, discuss your ideas with your instructor.