Making observations

The point of this lab exercise is for students to practice the general scientific techniques required of them in general lab courses. It uses easily obtained household items. It is important to point out that students must make some of their own choices when conducting this experiment such as how often to take measurements, how precisely to record their observations, etc. These choices are an important part of doing science. Students will:

- set up a simple experiment
- make measurements, observations, plots, interpretations
- keep data organized
- explore reproducibility, uncertainty, errors

Boiling Water Lab Experiment

These are the materials you need for this lab: water, a pot, a thermometer, a stove or other heat source, a watch or other timer. A digital thermometer like this one (photo coming) can be purchased for less than $10 at Lowe's or another similar store.

Part 1 Procedure

1. Measure a volume of water (you can choose the volume) into your pot. Record this volume.
2. Measure the starting temperature of the water. Record this measurement
3. Put the pot on the stove and turn on the stove (you can choose how high to turn it up, but keep the level constant). Describe what you did in a way that another person could follow you or that you could go back and reproduce your own steps.
4. Measure the temperature of the water at regular intervals. It is up to you to decide how often you need to make measurements. Record these measurements.
5. When the water boils, note the time, and remove the pot from the heat. Record this time and record the temperature.
6. Continue to make regular measurements of the temperature of the water until it cools back down to the initial temperature from step 2. Record these measurements.
7. Measure the volume of water at the end of your experiment. Record this volume.

Part 1 Data and Questions

Initial volume of water:

Final volume of water:

Starting water temperature:

Final water temperature:

Stove procedure:

The table below is a guide. You may make as many measurements as you wish. Be sure to record units of time and temperature so another person would know exactly what you measured.

Elapsed Time	Temperature

Answer the following questions:

1. How did you measure the volume of water into your pot? Why did you choose the volume you chose? How precise do you think your measurement was?
2. Was it easy or difficult for you to decide when to "know" that the water was boiling? How did you decide? (i.e. based on observing the water or based on observing your thermometer, or another way?)
3. When you observed the water boil, did your thermometer read 100C or 212F? If not, discuss possible reasons why not.
4. How much time elapsed between the beginning of the experiment and the time when the water boiled?
5. How much time elapsed between the boiling time and the end of the experiment?
6. How often did you record a temperature measurement? Did you decide how often to take data before you began your experiment? Did you change your measurement interval during the experiment? If you did, why did you?
7. If you were going to do this experiment again, would you change anything about your procedure?
8. Plot your data for this experiment. Your plot must have a title, a labeled x axis, and a labeled y axis. You must choose how to represent your data on this plot. I suggest that the best way to represent your data is with a scatter plot in which each measurement of temperature at a particular time is recorded with symbol.
9. If you were going to do this experiment again, discuss whether you would change anything about your procedure and why.

Part 2 Procedure

1. Now pick an experimental variable, such as the initial volume of water in the pot, the kind of pot, or how high to turn on the stove. Record which experimental variable you chose.
2. Change this variable from your first experiment and repeat the experiment.
3. Change this *same variable* at least one more time and do the experiment again. (three total experiments)
4. This time I'm not giving you a table to fill out as I did in Part 1. It is up to you to construct a table and and to keep track of other important information on your own in whatever way works best for you.

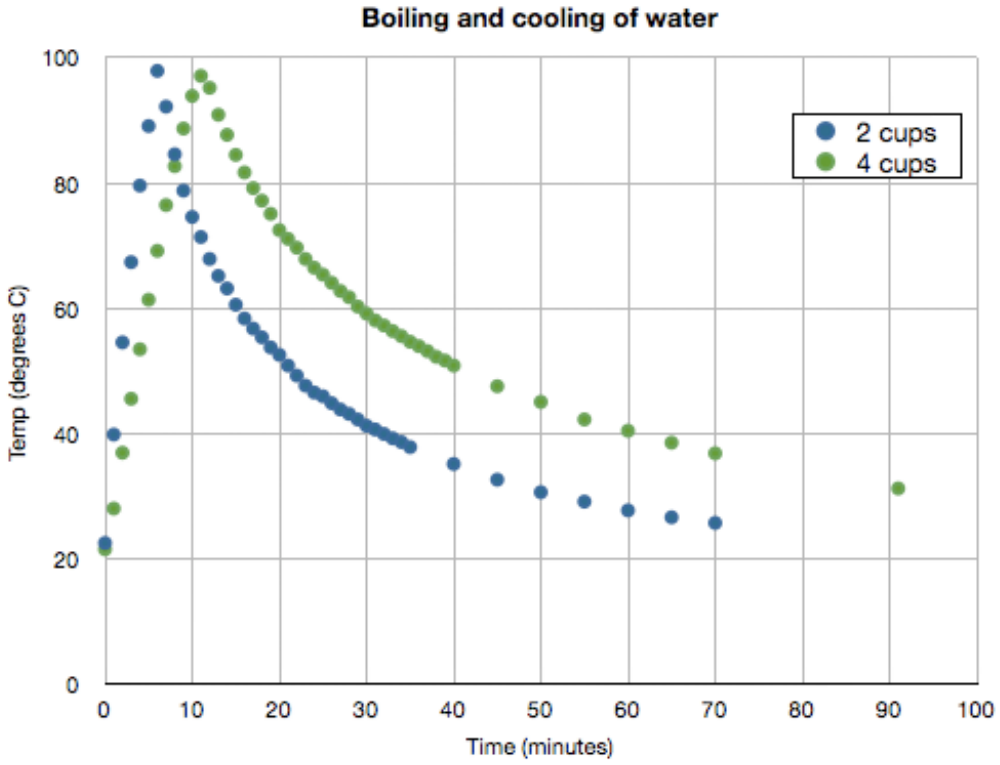
Part 2 Questions

8. Plot the data from each of the experiments in Part 2.
9. Describe which experimental variable you changed and how the change you made affected your results.
10. Eyeball a best fit function to the the water-heating-up data for each experiment. What do these functions look like (linear? curved? could you write an equation down to describe them?) What is indicated by the shapes of these functions? Were they affected by the changes you made between experiments?

11. Eyeball a best fit function to the the water-cooling-down data for each experiment. What do these functions look like? Are they all similar to each other? Do they have the same form as the water-heating-up functions? Discuss why or why not.
12. Speculate about what would have happened if you had chosen a different experimental variable to change. Predict how changing that other experimental variable would have changed your results.
13. How could you improve this experimental design?

Notes for the instructor:

See an example plot below of two experiments in which the initial volume of water in the pot was varied.



Time vs. temperature for 2 cups (blue) and 4 cups (green) of water in an open saucepan on a gas stove. During each experiment, the stove was turned on to the "medium" setting and left there until the water boiled, at which point the stove was turned off for the duration of the experiment.

Extending this lab

Group work:
Form students into groups between Parts 1 and 2 and ask them to share their initial data and plots with each other via email or a threaded discussion. Suggest to them that they divide up which experimental variable to change so they each explore a different parameter space. Suggest to

them that they discuss measurement-making strategies (how often to record, finding a consistent and reproducible way to decide when the water boils) and and how to reconcile datasets produced with different setups (what if some people have a gas stove and some people have electric? what if some people took all their readings in Celsius and others used Fahrenheit? What if some people didn't use a digital thermometer?) Then have the students each do Part 2 on their own after having discussed a best strategy among their group. This kind of group work succeeds in an online setting because discussions and comparisons are less burdensome on separated students than collaboration on the actual lab work.

For students with little quantitative preparation:
If your students are unfamiliar with spreadsheet programs or other electronic means of making plots, lead them through the construction of a plot by hand on graph paper which they can hopefully submit by electronic means somehow. You may start by asking them to find the ranges of values of time and temperature, then asking them to make the axes, then asking them to plot their points.

For upper level students:
This kind of experiment can be extended to discussions of the specific heat capacity of water, important in the global climate system. Students can be asked to speculate about the form of the heating and cooling functions and why they take the form they do.

For grad students:
This kind of experiment can be used in a discussion of ethics in science. Here's one way to do it: When you assign this lab, make sure the students know that their data table and plot will be shared with their classmates during a discussion at the end of the activity. Then, pick a secret group of students and have them falsify their data. When the class convenes to discuss, is it obvious to the other students which data is not real? Begin this discussion with questions about reproducibility and ask whether all plots look similar, what the reasons for differences could be, etc. Instructor participation in the discussion portion of this exercise is key because you don't want students to come away with the conclusion that all reproducibility issues are the result of ethical violations.