The Scientific Method

* The scientific method is a fancy name for “figure out what happens by trying it.”
* In the middle ages (400-1300) western “scientists” were called “philosophers.” These were scholars or thinkers who decided what was “correct” by arguing and debating with each other. Little or no experimentation was done.
* There is evidence of actual experimental science, including systematic observations and data collection in the Middle East in the early 500s, and in China circa 1000-1300. Unfortunately most of the collected histories of science focus on the work done in Europe in this period.
* In Europe it was not until the Renaissance which began in the 1300s and ended in the 1500s that scientists like Galileo Galilei and Leonardo da Vinci started using experiments instead of argument to decide what really happens in the world.

**Elements of the Scientific Method**

It is important to note that these “steps” are not prescriptive. Science is creative and fluid in nature. Think of these more as a rough guideline of how scientific reasoning occurs.

* Notice something interesting.
* Make careful observation of that something.
* Wonder how that interesting thing works or relates to other things.
* Perhaps even come up with a possible explanation, this is called a ***hypothesis***.
* Think of a way to test how that relationship can be tested.
* Design and perform an experiment that will have different outcomes depending on the parameter(s) being tested.
* Repeat the experiment, varying your conditions in as many controlled ways as you can.
* If possible, come up with a model that explains and predicts the behavior you observed.
* Share your model, your experimental procedures, and your data with other scientists. Some of these scientists may:
  1. Look at your experiments to see whether the experiments really can distinguish between the different outcomes.
  2. Look at your data to see whether the data really do support your model.
  3. Try your experiments or other related experiments themselves and see if the results are consistent with your model.
  4. Add to, modify, limit, refute (disprove), or suggest an alternative to your model.

This process is called “peer review.” If a significant number of scientists have reviewed your claims and agree with them, and no one has refuted your model, your model may gain acceptance within the scientific community. At this point your model can be called a ***scientific theory***.

* Make predictions based on the theory and test those predictions.

Notice that the hypothesis is only an optional step. It is possible (and sometimes useful) to have a hypothesis before performing an experiment, but an experiment is just as valid and just as useful whether or not a hypothesis was involved.

In order to highlight the fact that the scientific method is NOT a set of steps, rather a guideline, consider the following example of an “experiment” that follows the scientific method.

1. **Asking a Question** about the world around us. For example “*Is the Earth flat?”*

2. Making a **hypothesis**. A hypothesis is a possible explanation or answer to the question. *“I think that the Earth is flat”*

3. Making **predictions** about the future using the hypothesis. *“If the Earth is flat it must have an edge”*

4. Design and perform **controlled experiments** to test the predictions. “*I will sail my boat to the edge of the world, look over the edge and throw a tomato into the abyss”*

5. Make observations and collect data. “*I have sailed my boat for weeks and months, and have still not reached an edge”* and *“After a very long time of sailing and walking and sailing, all in a straight line, I have returned to the same spot.”*

6. **Analyze** the data from your experiment. *“It seems that perhaps the Earth has no edges”*

7. Draw **Conclusions**. *“If there are no edges the Earth cannot be flat”* Do your observations support the hypothesis? Repeat steps 2-7 until you have a hypothesis that works.

Controlled Experiments:

The entire goal of a controlled scientific experiment is “FAIRNESS”. Imagine if you wanted to test which car had the best fuel economy. It would not be fair to test the cars with one of them towing a heavy trailer and the other one not, or to have one diving up a steep hill and the other on flat land. In both of those examples we are introducing some other factor (the trailer or the hill) or **variable** to the test.

For a “fair” test you should only have two **variables**. In this case 1. The different cars and 2. The fuel economy. The test should strive to keep all other factors equal, or **controlled for**. For example: The speed at which the cars are driven, the outside temperature, the driving style, air-conditioning off or on…

This is really all that is meant by a **controlled scientific experiment**. The two variables we are testing for are called the **independent variable** and the **dependent variable**. All of the other variables are called **controlled variables**. The biggest challenge in designing a good, fair experiment is identifying and correctly controlling for as many variables as possible.

**Independent Variable:** One of the two variables the experiment is designed to test for. The independent variable is the parameter that the experimenter DIRECTLY MANIPULATES or changes.

**Dependent Variable:** One of the two variables the experiment is designed to test for. The dependent variable is the parameter that the experimenter needs to observe and measure to see how it has changed. Also known as the responding variable.

A controlled experiment is designed to test how changes to the **independent variable** affect the **dependent variable**.

**Controlled Variables:** These are all of the factors, other than the independent variable, that could cause changes in the dependent variable. For the experiment to be fair the experimenter must keep these variables constant.

**Experimental Control:** Not all experiments have an experimental control. In the case that there is some accepted “standard” or “normal”, the standard should be included in the experiment as the experimental control. For example if a scientist is testing how different fertilizers added to water affect plant growth, plain water would be the experimental control.