Scientific Method:
Pre-Lab

Chances are you have studied the steps of the scientific method every year of grade school and are also studying it now in lecture. Rather than reviewing that material again, we will focus here on applying the practical elements of the scientific method to real experiments. Our three main topics will be variables, control experiments, and the hypothesis.

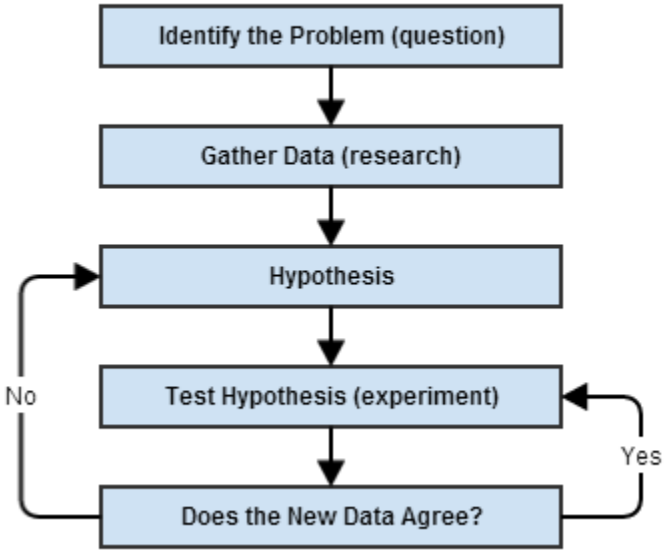

Figure 1: Steps of the Scientific Method (Michael Fullerton Creative Commons 4.0)

VARIABLES

When designing an experiment, there are many different options of how to do things. How much water you pour in the cup, how long you wait, what you measure, how you measure it, all of these are variables. The three types of variable are independent, dependent, and control.

The **independent variable** is the condition you are testing. For example, if you are testing which brand of dog food dogs like best, the independent variable is the different brands of dog food. If you are testing which brand of fertilizer works best, the independent variable is the different types of fertilizer. Another way to recognize this variable is that this is the condition you are "changing on purpose" between each experiment. The independent variable is also called the **experimental variable**.

The **dependent variable** is the data you are taking on your experiment. This is the information you will use to make your conclusions later. If you are testing which brand of dog food dogs like best, the dependent variable might be how much of each brand the dogs eat, or possibly which of the brands the dog eats first. If you are testing which brand of fertilizer works best, the dependent variable might be how tall each plant grows or how much fruit they produce. Another way to recognize this variable is that this is the value that you think will change based on the changes you make to the independent variable. You think that this value "depends" on the condition you are testing.

The **control variables** are elements of the experiment that you take *deliberate action* to keep the same. Back to our dog food test, putting the same amount of food in each bowl is a control variable. In the plant experiment, giving the plants the same amount of water is an important control variable. Things that stay the same without you taking deliberate action do not count as control variables. Essentially, if you don't identify them ahead of time, they are not control variables. Also, control variables are usually things you think might alter the outcome of the experiment. You can't control everything, so you have to focus on those things that you think are actually important.

Most of the errors made when designing or reporting on experiments involve the three types of variables. Sometimes a second independent variable sneaks into the experiment. This is usually something that should have been a control variable, but the experimenter didn't pay attention to it. In the plant fertilizer experiment, if some fertilizers are liquid and others are solid, the plants receiving the liquid fertilizer are also receiving more water. This is because the fertilizer is dissolved in water. The total amount of water must be adjusted for these plants so that you aren't accidentally making water amount an independent variable.

Another common error is failing to plan out the dependent variable. In our dog food experiment, failing to define what "better" means ahead of time can cause problems. When putting out three types of dog food at the same time, is better defined by which food the dog eats first or which one the dog eats the most of?

One final common cause of error is waiting until the end of an experiment to name the control variables, then choosing things which were coincidentally the same. In our plant fertilizer experiment, you shouldn't list "room temperature" as a control variable. True, the plants were all grown at the same temperature because they were in the same room, but you didn't take deliberate action to make this so.

Experiment Note - For every experiment you do, you will be required to identify all three types of variables *before* you begin the experiment.

CONTROL EXPERIMENTS

Control experiments are used to set the baseline for your experiments and also to make sure your measurement for the dependent variable works. The **negative control** lets you know the

value of the independent variable without treatment. In our plant fertilizer experiment, a plant with no fertilizer serves as the negative control. This lets you know how much a plant should grow on its own. The negative control is also sometimes called the **control group.** When testing the effectiveness of any treatment, the group that does not receive the treatment is called the control group. **A positive control** lets you know that your basic experiment conditions are valid. In the plant experiment, the plant without fertilizer also serves as a positive control. If it doesn't grow at all, you know there is a problem with your setup and none of your fertilizer results will be useful. Some experiments do not have control experiments. Our dog food experiment might not have any.

These positive and negative control experiments have nothing to do with *control variables*. The fact that they both contain the word "control" is a coincidence.

HYPOTHESIS

A **hypothesis** is a statement about the results of an experiment made *before* the experiment is performed. It is a prediction of the outcome based on what you already know. A good hypothesis usually includes the dependent and independent variables. For example, "When given the choice between three kinds of dog food, dogs will eat more of the Purina than of Kibbles and Bits or Kroger brand," names the independent variable (kinds of dog food), the independent variable (how much is eaten), and a prediction of the outcome.

A common mistake in making a hypothesis is making a question. "Which fertilizer works best?" is not a hypothesis. "Truegreen works better than Vigoro," is a hypothesis. A better hypothesis would be, "Plants given Truegreen fertilizer grow taller than plants given Vigoro." This hypothesis is better because it includes our variables.

Another common mistake is naming an independent variable that can't actually be tested. For example, our hypothesis about dog food should never be, " . . . dogs will like Purina better than Kibbles and Bits or Kroger brand." You cannot tell what a dog "likes." You can only say what the dog does; it eats more of Purina than the others. You can later infer something about likes or dislikes, but that is not actually what you are testing. If your hypothesis includes words about mental state (likes, hates, loves, wants to, etc.), it is usually not testable.

Experiment Note - For every experiment you do, you will be required to state the hypothesis *before* you begin the experiment.

LEARNING GOALS

By the end of this unit, you should be able to do the following:

1. Describe the steps of the Scientific Method.

2. Define dependent and independent variables.

3. Write a testable hypothesis.

4. Describe the meaning and purpose of experimental controls.

5. Gather data from an experiment and analyze the results.

6. Determine whether data support or reject the experimental hypothesis.

IN THIS LESSON

In this lesson, you will be running a virtual simulation measuring the growth of flowers under different conditions in order to complete the Scientific Method Activity Sheet. Once you have completed the experiment, you will share your results with the class using the Google docs link in the Scientific Method Discussion Board.

Scientific Method Virtual Lab Activity Questions

Use the following virtual activity to practice using the scientific method to answer a question.

http://www.biologycorner.com/worksheets/scientific_method_plant_exp.html#.U1p4L_ldXjJ

1. **What was the horticulturalist's observation that led to the plant growth experiment?**

2. **What is your hypothesis concerning plant growth?**

3. **What is the independent (experimental) variable?**
4. **What is the dependent variable?**
5. **What aspects (variables) of the experiment should you control?**

Fill in the table with your lab results.

Group (control or experimental)	Flower species	Pot type	Soil brand	Detergent (yes/no)	Plant 1 Height (cm)	Plant 2 Height (cm)	Average height (cm)
6.							
7.							

8. **What is your conclusion?**

REPEAT this experiment but choose a DIFFERENT independent variable.

9. **What is your new hypothesis?**

Fill out the data table below with your lab results.

Group (control or experimental)	Flower species	Pot type	Soil brand	Detergent (yes/no)	Plant 1 Height (cm)	Plant 2 Height (cm)	Average height (cm)

10. **Write out your results in words. Use the average plant heights in your statement.**

11. **Finally, run one trial growing marigolds, use terracotta pots filled with Miracle Grow and detergent. Record your name and the plant heights for each flower in this Google doc link: (YOU NEED TO CREATE A UNIQUE LINK FOR YOUR CLASS). Calculate the**

average plant heights for the class data. How does your data compare to the class average?

Scientific Method Video and Pre-lab Study Guide Questions

12. **What are the essential steps of the scientific method?**

13. **Define hypothesis. How should a hypothesis be worded?**

14. **Why is it important to test one variable at a time when doing an experiment?**

15. **Why is it better to conduct an experiment more than once?**

Discussion/Research Question

Detergents are commonly washed down the drain with waste water and can be exposed to both plants and animals. What affect might detergent pollution have on aquatic animals? Humans? Create a testable hypothesis for your idea.

FOR INSTRUCTORS

"The Scientific Method Online Lab Activity" is a lesson that uses an online experiment simulation and worksheet to have students create and conduct an experiment on pollution and plant growth. This lesson covers a number of the Vision and Change Core Competencies for Biology teaching.

Core 1. Ability to apply the process of science: Students conduct and modify an online experiment and submit homework discussing hypothesis testing, results and conclusions.

Core 2: Ability to use quantitative reasoning: The students analyze and interpret the class data for the experimental means.

Core 4: Ability to tap into the interdisciplinary nature of science: The online experiment is based on understanding the effects of pollution on plant growth which is related to the sister science of Environmental Biology.

Core 6: Ability to understand the relationship between science and society: As part of the homework, students are asked to reflect on how humans may be affected by water pollution and to create a testable hypothesis for their hypothesis.

Activity Answers:

1. The observation was that soapy runoff from a nearby carwash was running into his flower beds.
2. The students hypothesis should be that "Detergent will either increase OR decrease the height of the flower plants." Watch out for them using "effect flowers" or "kill plants". They need to recognize that the hypothesis must be based on what they are specifically measuring in the experiment.
3. The independent variable is Detergent vs No detergent (Presence of detergent).
4. The dependent variable is the height of the flower plants.
5. There are many answers. Obviously, in the experiment the students should use the same species of flower, the same type of pot and the same brand of soil! In addition, they may state that they will control the number of growing days, the same amount of water, etc.
6. Student data
7. Student data
8. Their conclusion must be based on their data. It is best if they use actual numbers. For example "Marigolds exposed to detergents grew 2 cm shorter than marigolds that were not exposed". It is acceptable to answer "Flower plants grown with detergent are shorter than flower plants grown without detergent". It is NOT acceptable to say "Detergent is bad for flowers".

9. Second hypothesis. Should be comparing flower species, pot type or soil brand.

10. Students should write out their results table information in paragraph form. They should describe the flower species, pot used, soil, detergent presence and compare the flower heights.

11. Students should calculate the average for the class by adding up all the values and dividing by the number of entries. They should then discuss how their numbers differ (or not) from the classes' and discuss reasons for those differences.

12. The steps of the scientific method are 1) Make an observation or ask a question 2) conduct background research 3) Create a hypothesis 4) Run an experiment and 5) Analyze the results

13. A hypothesis is a proposed explanation that can be tested using an experiment. A hypothesis should be worded to include the independent and dependent variables of the experiment and must choose a result. For example "Students who see the math tutor every week will score higher on the math test than student who do not use the tutor."

14. It is important to test one variable at a time so you can determine which of the variables is affecting the outcome of the experiment.

15. It is always better to repeat an experiment since repetition reduces the likelihood of errors and increases the reliability of the results/conclusions. In addition, repetition will show the range of values that can occur under a set of conditions (how accurate are your results).