Name ________________________

The Scientific Method

Learning Objectives:

1. Describe science as being a process of proposing and testing hypotheses.
2. Distinguish between statements that are testable by science and those that are not.
3. Describe the meaning and purpose of experimental controls.
4. Write a testable hypothesis.
5. Design an experiment to test a hypothesis.
6. Gather data from an experiment and analyze the data using statistics.
7. Create a graph using data gathered during an experiment.
8. Define "statistical significance" and describe what statistics describing an experimental result can and cannot tell us about the hypothesis.

Pre-Laboratory Reading

The word "science" is derived from a Latin verb *scientia*, meaning "to know." Science is a way of knowing about the world. There are many other ways of knowing – in other words, of finding truth – including faith, philosophy, and cultural tradition. All of these ways of knowing help us understand different aspects of our world.

The essence of science as a way of knowing is the formulation and testing of statements called **hypotheses**. A hypothesis is a tentative explanation of how something works or of the cause of an event. Scientific hypotheses must be testable. In other words, hypotheses must be made in such a way that observations of the natural world can help us support or reject them. Hypotheses are tested via **objective** observations; that is, observations that when made by many different, independent people would produce the same results.

Many cleansing products on the market today advertise that they "kill germs" or, more specifically, that they are "antibacterial." This label typically indicates that these products contain triclosan or another related antiseptic chemical. Consumers concerned about food poisoning or other bacteria-caused illnesses preferentially purchase these products based on their assumption that the following hypothesis is true:

Antibacterial soap kills more bacteria on hands than standard hand soap.

Good scientists are usually skeptical of untested hypotheses. For instance, there are reasons to doubt the hypothesis that antibacterial soap is a more effective cleanser. The action of hand washing *physically* removes bacteria from hands. It is not clear that the chemical makeup of the soap (outside of the fats, oils, and alkali that all soaps contain) is an important factor in disinfecting hands. Without testing the hypothesis, there is no way to determine whether it is correct.

The first step in testing a hypothesis is making a **prediction** about the observations one would expect to make if the hypothesis was correct. You can think of a prediction as the "then" part of an "If . . . then . . ." statement. In other words, "If this hypothesis is true, then I expect to observe . . ." A prediction forms the basis for evaluating the truth of any statement. The prediction of the hypothesis that antibacterial soap kills more bacteria on hands than standard hand soap is that *hands washed with antibacterial soap will have fewer bacteria on them than hands washed with standard soap*. Many (but not all) scientific hypotheses can be tested through experimentation. An **experiment** is a situation set up by a researcher solely for the purpose of testing a hypothesis. The hypothesis about antibacterial soap is testable by experiment.

When a hypothesis can be tested through experimentation, the most effective way to remove ambiguity (the chance that results could be interpreted in more than one way) from the results is to design a controlled experiment. **Control** indicates that the researcher works to ensure that all subjects in the experiment are treated identically (except for the experimental treatment). In other words, a control helps to verify that the effect of an experimental treatment is due to the treatment itself and not some other factor. One common control in an experiment is to keep both the subjects and the technicians performing the experiment unaware of which individuals are receiving the experimental treatment and which are not. Experiments designed in this manner are called **double blind**, because the participants cannot "see" what outcome is expected and, even unintentionally, bias the results.

Measurements collected from tests of hypotheses are called **data**. A **graph** is a "picture" of the data collected. Data collected from experimental groups and control groups are summarized and compared using the tool of **statistics**. Statistics is a specialized branch of mathematics designed to help scientists relate the results of a limited experiment to a larger population. Individuals in an experiment make up a **sample** of the population they are taken from. A sample is always an imperfect reflection of the whole population. As a result, there are two reasons that experimental and control samples may differ: (1) the experimental treatment has a real effect; or (2) by chance, individuals selected for the experimental group are quite different than the individuals selected for the control group. If a statistical test indicates that there is a very low likelihood that reason (2) from above is true, the results of an experiment are termed **statistically significant**.

PRACTICE IDENTIFYING AND CREATING SCIENTIFICALLY TESTABLE HYPOTHESES

A. Review these statements with your laboratory partners and be prepared to share your answers with your laboratory instructor and/or other students.

B. For each statement, determine whether it is a scientific hypothesis as written, and if not, why not.

C. If the statement is not a scientific hypothesis, try to modify the statement so that it is testable.

D. Are any hypotheses impossible to test objectively?

1. It is wrong to perform medically unnecessary cosmetic surgery.

2. Biology lab is more fun than a barrel of monkeys.

3. Plants that are spoken to regularly grow more rapidly than plants that are not spoken to.

4. Women are more intelligent than men.

PREPARING TO DESIGN AN EXPERIMENT

In the introduction to the lab, we put forth the following scientific hypothesis:

> *Antibacterial soap kills more bacteria on hands than standard hand soap*.

A. Discuss the following questions with your lab partners and be prepared to share your answers with the lab instructor and other students.

1. What objective measures could we use to test the hypothesis about the cleansing power of antibacterial soap?

2. If the hypothesis is correct, what would you predict the outcome of the test to be?

3. To test this hypothesis, we could simply survey everyone in lab regarding his or her use of this soap. Presumably, at least some of the class almost always uses antibacterial hand soap and some almost never use this type of soap. After we found these two classes of people, we could simply compare the number of bacteria found on their hands. Why is this a poor test of the hypothesis?

4. We could test the hypothesis by designating half the class as "antibacterial soapers" and the other half as "regular soapers," having everyone wash their hands with the soap they have been assigned to, and then comparing the number of bacteria found on the hands of members of each group. However, this approach is also flawed. Why?

DESIGN AND PERFORM A CONTROLLED EXPERIMENT

The last discussion exercise should have led you to consider some of the factors you will need to control when testing the hypothesis that antibacterial soap kills more bacteria on hands than standard hand soap. Now you should be prepared to design a well-controlled experiment to test this hypothesis.

First, you will need a short lesson on how bacteria levels can be counted.

- Bacteria are single-celled organisms that are much too small to be seen with the naked eye, and many can only be seen under the highest magnification of a typical light microscope.
- Bacteria reproduce rapidly when in contact with a nutrient source.
- If an individual bacterial cell is transferred to a gel-like nutrient source, the cell will multiply into millions of descendants, producing a colony of cells that is visible to the naked eye. A bacterial colony that arose from a single cell typically appears as a distinct circular dot on the surface of the gel-like nutrient source (called **agar**).
- Thus, the number of bacteria on a given surface can be estimated by transferring those bacteria to a petri dish filled with nutrient agar gel, giving those cells 24-48 hours to multiply, and then counting the number of visible colonies on the plate.

A. Work with your lab partners to design a controlled experimental test of the hypothesis.

Materials available:

- Liquid hand soap: one containing triclosan and a similar formula soap minus triclosan (Note: most of these soaps instruct users to rub the lather on their hands for 30 seconds to get the maximum effect).
- Petri dishes filled with nutrient agar (two per lab team)
- Sterile cotton swabs for transferring bacteria from hands to petri dishes
- Sterile water to swab dirty hands with
- Permanent markers

B. Write an outline of your experiment below. Be prepared to share this design with the lab instructor and/or your classmates.

C. When you have finished, your lab instructor will lead a discussion that will generate a class protocol based on the common and best elements of each plan.

D. Follow the class protocol to perform an experimental test of the hypothesis. Results will be available in the next class period.

COLLECT EXPERIMENTAL RESULTS

A. Count the number of bacterial colonies on your agar plate and record them here:

- Before washing ________________
- After washing _________________

B. What was your treatment group? ______________________

C. Input your data into an Excel spreadsheet.

D. Fill in Table 1.1, summarizing all of the data collected by the class. Recall that the number of colonies on the plates is approximately equivalent to the number of bacteria initially transferred.

Lab Team Members	**Bacteria Transferred Before Washing**	**Bacteria Transferred After Washing with Soap X, OR …**	**Bacteria Transferred After Washing with Soap Y**
Total number of colonies (add up all of the numbers in each row)			
Count (number of values you added to get the result above)			
Average (Divide the total number of colonies by the count)			

SUMMARIZE EXPERIMENTAL RESULTS

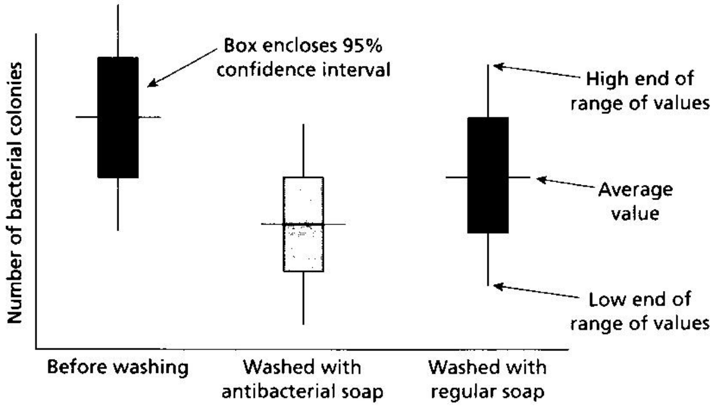
A. Calculate the average number of colonies in each treatment group by summing all values in a column and dividing by the number of students in each treatment group.

- Before _______
- Group X ________
- Group Y ________

B. Ask your lab instructor which soap was antibacterial and which was standard.

- Soap X ___________________________
- Soap Y ___________________________

C. Create a box-and-whiskers graph using Excel to summarize the data in the preceding table by using the template below.



D. Fill in the table below, using the confidence interval data generated by your class.

	Before Treatment	**Washed with Antibacterial Soap**	**Washed with Standard Soap**
Average number of colonies per plate			
95% confidence value (available from Excel spreadsheet)			
Range of values (the lowest and highest values in the data set)			

- The "95% confidence interval" is the range of values that has a 95% chance of containing the "true" population average (in other words, the average number of bacteria found if we had performed this experiment with the entire human population as our sample).
- If the confidence interval for our sample means overlaps, then the average difference between the two sample means is not significant. In other words, there was no difference between the effectiveness of antibacterial soap and standard soap.