Experimental Design and Controlled Experiments

The goal of science is to investigate and understand the natural world, to explain the events in the natural world, and to use those explanations to make useful predictions. Scientists use a process of inquiry that includes making observations and forming testable explanations (*hypotheses*). The process is necessarily repetitive: In testing a hypothesis, more observations may inspire revision of the original hypothesis or formation of a new one, thus leading to further testing. In this way, scientists circle closer and closer to their best estimation of the laws governing nature.

Every scientific investigation begins with a question that the scientist wants to answer. To answer the question, the scientist often begins with observation, the process of gathering information about events. The information gathered from observations is called **data**. There are generally two types of data. **Quantitative** data are expressed as numbers, obtained by counting or measuring. **Qualitative** data are descriptive and involve characteristics that can't be counted, like color or appearance. A reliable scientific study can be performed when it is based on the gathering of data and not on opinion; the study must be **objective**, not **subjective**.

1. [SP 3] Consider the following questions with your partner and decide which of them you think can be answered by scientific inquiry. How did you decide which questions can be answered scientifically?
a) What is the cause of AIDS?
b) Are serial killers evil by nature?
c) Why is the grass green?
d) What is the best recipe for chocolate chip cookies?
e) By how much will the average world temperature increase by 2020?
f) How can the maximum yield be obtained from a wheat field?
g) Does watching television cause children to have shorter attention spans?

After making initial observations and collecting data, researchers propose a **hypothesis**, which is a proposed scientific explanation for a set of observations - a possible answer to the original question. A scientific hypothesis must be proposed in a way that enables it to be tested and it is usable only if the hypothesis can be proven false. It must be able to lead to a prediction that can be tested by making additional observations or by performing an experiment. The nature of science is such that we can prove a hypothesis false by presenting evidence from an investigation that does not support the hypothesis. We do not try to prove a hypothesis true. For instance, imagine the hypothesis "All mice have tails." This can never be proven <u>true</u> because we can never observe every mouse. It can, however, be proven false by observing a single mouse without a tail. Some hypotheses are tested by performing controlled experiments to gather more data. Some hypotheses are ruled out while others are supported and confirmed. In most cases, the work of one researcher will be followed and improved upon, leading to new hypotheses and, sometimes, the rejection of previous hypotheses.

2. [SP 3] After reading the paragraph above, how would you say you *should* have made your decision about each one in Q. 1?

3. [SP 3] Identify which of the following could be scientific hypotheses. Provide reasons for your decisions.
a) Plants absorb water through their leaves as well as through their roots.
b) Mice require calcium for developing stronger bones.
c) Dogs are happy when you feed them steak.
d) An active volcano can be prevented from erupting by throwing a virgin into it during each full moon.

4. [SP 3] Write a hypothesis for each of the following:
a) Guinea pigs are kept at different temperatures for 6 weeks. Percent weight gain is recorded.
b) Batches of seeds are soaked in salt solutions of different concentrations and the number of seeds that germinate is counted for each batch.
c) People seem to behave differently during a full moon compared to other times of the month.

Scientific knowledge is thus an accumulation of evidence in support of hypotheses: it is not to be regarded as absolute truth. Hypotheses are accepted only on a trial basis. Future investigations may be able to prove any hypothesis false. If a hypothesis is well tested and consistently supported by observable evidence, the hypothesis is considered a theory. A theory is the best explanation for a set of observations and is accepted in the scientific community until proven false.

5. [SP 3] State the difference between a hypothesis and a scientific theory.

In summary, the questions addressed by scientific inquiry are based on observations or on information gained through previous research, or on a combination of both. Just because a question can be answered doesn't mean that it can be answered *scientifically*.

Whenever possible, a hypothesis should be tested by an experiment in which only one variable is changed at a time. The variable that is deliberately changed is called the **independent variable**. The variable that is observed and that changes in response to the independent variable is called the **dependent variable**. Changes in the dependent variable *depend* on changes in the independent variable. An easy way to think about this is to say "the change I saw in _____ 'depends' on _____." For example, "the change I saw in my heart rate depends on how long I ran on the spot." Heart rate is the dependent variable because it *depends* on how long you ran on the spot, the independent variable. The dependent variable is the one the investigator measures, counts, or records. The independent variable is the one that is purposely allowed to change. All other variables should be kept unchanged or controlled. This type of experiment is called a **controlled experiment**. **Controlled variables** are factors that are kept constant, so that any changes in the dependent variable can be attributed to the changes the investigator made in the independent variable and to that variable only.

6. [SP 3] Identify the independent and dependent variables in the following examples.
a) Height of bean plants is recorded daily for 2 weeks.
b) Guinea pigs are kept at different temperatures for 6 weeks. Percent weight gain is recorded.
c) The diversity of algal species is calculated for a coastal area before and after an oil spill.
d) Light absorption by a pigment is measured for red, blue, green, and yellow light.
e) Batches of seeds are soaked in salt solutions of different concentrations, and germination is counted for each batch.
f) An investigator hypothesizes that the adult weight of a dog is higher when it has fewer littermates.

7. [SP 3] Why would a scientist have to be sure there is only one independent variable in an experiment?

In order to be able to make a conclusion about the independent variable, we must be able to compare the results to some group that was not subjected to that variable. This group is called a **control group**. The control group is identical to the experimental group except the independent variable is eliminated or held constant. Everything else must remain the same so that the results of the control group can be compared to the results of the experimental group.
For example, during drug testing, scientists will try to have two groups as similar as possible, then allow one group to try the drug. A control group allows the investigator to say "the only difference between the two groups was the drug, so the results must be due to the drug."

8. [SP 3] Identify an appropriate control group for each of the following examples:
a) The effect of light intensity on photosynthesis is measured by collecting oxygen produced by a plant.
b) The effect of NutraSweet sweetener on tumor development in laboratory rats is investigated.
c) Subjects are given squares of paper that have been soaked in a bitter tasting chemical. The investigator records whether each person can taste the chemical.
d) A solution is made up to simulate stomach acid at pH 2. Tums antacid is added to the solution in small amounts, and the pH is measured after each addition.

Another essential aspect of experimental design is **replication**. Replicating the experiment means that the scientist repeats the experiment numerous times using exactly the same conditions to see if the results are consistent. Being able to replicate a result increases our confidence in it. However, we shouldn't expect to get exactly the same answer each time, because a certain amount of variation is normal in biological systems. Replicating the experiment lets us see how much variation there is and obtain an average result from different trials.
A concept related to replication is **sample size**. It is risky to draw conclusions based upon too small a sample size because the individuals in your experiment may not represent the population in general.

9. [SP 3] A group of students hypothesizes that the amount of alcohol produced in fermentation depends on the amount of glucose supplied to the yeast. They want to use 5%, 10%, 15%, 20%, 25%, and 30% glucose solutions to see which one results in the greatest alcohol production.
a) Propose a hypothesis to precede this experiment.
b) What is the independent variable?
c) What is the dependent variable?
d) What control group should be used?
e) What variables should be controlled?