

BIOLOGY 163 LABORATORY

THE EXPERIMENTAL METHOD

Throughout the laboratory portion of BI 163, you will be conducting a number of experiments. Science proceeds by use of the experimental method. This handout provides a summary of the steps that are used in pursuing scientific research. This general method is used not only in biology but in chemistry, physics, geology and other hard sciences.

To gather information about the biological world, we use two mechanisms: our sensory perception and our ability to reason. We can identify and count the types of trees in a forest with our eyes, we can identify birds in the rainforest canopy with our ears, and we can identify the presence of a skunk with our nose. Touch and taste help us experience the biological world as well. With the information we gather from our senses, we can make inferences using our reason and logic. For instance, you know that you see palm trees in tropical and subtropical regions and can infer that palm trees will not be found in central Maine because of the harshness of our winter.

Our reason allows us to make predictions about the natural world. Scientists attempt to predict and perhaps control future events based on present and past knowledge. The ability to make accurate predictions hinges on the seven steps of the Scientific Method.

Step 1. Make observations. These observations should be objective, not subjective. In other words, the observations should be capable of verification by other scientists. Subjective observations, which are based on personal opinions and beliefs, are not in the realm of science. Here's an objective statement: It is 58 °F in this room. Here's a subjective statement: It is cool in this room.

The first step in the Scientific Method is to make objective observations. These observations are based on specific events that have already happened and can be verified by others as true or false.

Step 2. Form a hypothesis. Our observations tell us about the past or the present. As scientists, we want to be able to predict future events. We must therefore use our ability to reason.

Scientists use their knowledge of past events to develop a general principle or explanation to help predict future events. The general principle is called a **hypothesis**. The type of reasoning involved is called **inductive reasoning** (deriving a generalization from specific details).

A hypothesis should have the following characteristics:

- It should be a general principle that holds across space and time
- It should be a **tentative** idea
- It should agree with available observations
- It should be kept as simple as possible.
- It should be testable and potentially falsifiable. In other words, there should be a way to show the hypothesis is false; a way to disprove the hypothesis.

Some mammals have two hindlimbs would be a useless hypothesis. There is no observation that would not fit this hypothesis!

All mammals have two hindlimbs is a good hypothesis. We would look throughout the world at mammals. When we find whales, which have no hindlimbs, we would have shown our hypothesis to be false; we have falsified the hypothesis.

A hypothesis may also involve a cause-and-effect relationship. For instance, the drug Celebra helps relieve rheumatoid arthritis.

Step 3. Make a prediction. From step 2, we have made a hypothesis that is tentative and may or may not be true. How can we decide if our hypothesis is true?

Our hypothesis should be broad; it should apply uniformly through time and through space. Scientists cannot usually check every possible situation where a hypothesis might apply. Let's consider the hypothesis: All plant cells have a nucleus. We cannot examine every living plant and every plant that has ever lived to see if this hypothesis is false. Instead, we generate a **prediction** using **deductive reasoning** (generating a specific expectation from a generalization). From our hypothesis, we can make the following prediction: If I examine cells from a blade of grass, each one will have a nucleus.

Now, let's consider the drug hypothesis: The drug Celebra helps relieve rheumatoid arthritis. To test this hypothesis, we would need to choose a specific set of conditions and then predict what would happen under those conditions if the hypothesis were true. Conditions you might wish to test are doses administered, length of time the medication is taken, the ages of the patients and the number of people to be tested.

All of these conditions that are subject to change are called **variables**. To gauge the effect of Celebra, we need to perform a **controlled experiment**. The **experimental group** is subjected to the variable we want to test and the **control group** is not exposed to that variable. In a controlled experiment, the only variable that should be different between the two groups is the variable we want to test.

Let's make a prediction based on observations of the effect of Celebra in the laboratory. The prediction is: Patients suffering from rheumatoid arthritis who take Celebra will have less severe symptoms than those who take a placebo (a starch tablet instead of the drug).

Step 4. Perform an experiment. We rely again on our sensory perception to collect information. We design an experiment based on our prediction.

Our experiment might be as follows: 1000 patients between the ages of 50 and 70 will be randomly assigned to one of two groups of 500. The experimental group will take Celebra four times a day and the control group will take a starch placebo four times a day. The patients will not know whether their tablets are Celebra or the placebo. Patients will take the drugs for two months. At the end of two months, medical exams will be administered to determine if flexibility of the arms and fingers has changed.

Step 5. Analyze the results of the experiment. Our experiment produced the following results: 350 of the 500 people who took Celebra reported diminished arthritis as the end of the period. 65 of the 500 people who took the placebo reported improvement.

The data appear to show that there was a significant effect of Celebra. We would need to do a statistical analysis to demonstrate the effect. Such an analysis reveals that there is a statistically significant effect of Celebra.

Step 6. Draw a conclusion. From our analysis of the experiment, we have two possible outcomes: the results agree with the prediction or they disagree with the prediction. In our experiment involving the drug Celebra, the results support our prediction.

With present information, we accept our hypothesis as true. Have we proved it to be true? **Absolutely not!** There are always other explanations that can explain the results. It is possible that the more of the 500 patients who took Celebra were going to improve anyway. It's possible that more of the patients who

took Celebra also ate bananas every day and that bananas improved the arthritis. You can suggest countless other explanations.

How can we prove that our new hypothesis is true? We never can. **The scientific method does not allow any hypothesis to be proven.** Hypotheses can be disproven in which case that hypothesis is rejected as false. All we can say about a hypothesis which stands up to a test to falsify it is that we failed to disprove it. **There is a world of difference between failing to disprove and proving.** Make sure you understand this distinction; it is the foundation of the scientific method.

So what would we do with our hypothesis above? We currently accept it as true. To be rigorous, we need to subject the hypothesis to more tests that could show it is wrong. For instance, we could repeat the experiment but switch the control and experimental group. If the hypothesis keeps standing up to our efforts to knock it down, we can feel more confident about accepting it as true. However, we will never be able to state unequivocally that the hypothesis is true. Rather, we accept it as true because the hypothesis stood up to several experiments which could show it to be false.

Step 7. Report your results. Scientists publish their findings in scientific journals and books, in talks at national and international meetings and in seminars at colleges and universities. Disseminating results is an essential part of the scientific method. It allows other people to verify your results, develop new tests of your hypothesis or apply the knowledge you have gained to solve other problems.