Exercise 1A [Pre-Lab]

Scientific Investigation: Experimental Design

Adapted from Investigating Biology, Morgan & Carter, 6th ed.

Science assumes that biological systems are understandable and can be explained by fundamental rules or laws. Scientific investigation involves asking questions, making observations, developing explanatory hypotheses, and testing those hypotheses. Scientists closely scrutinize investigations in their field, and each scientist must present his or her work at scientific meetings or in professional publications, providing evidence from observations and experiments that supports the scientist's explanations of biological phenomena.

In this lab exercise, you will review the processes that scientists use to ask and answer questions about the living world and develop skills to conduct and critique scientific investigations. Like scientists, you will work in research teams, collaborating as you ask questions and propose explanations, design experiments, predict results, collect and analyze data, and interpret your results.

Asking a Question

For a question to be pursued by scientists, the phenomenon must be well defined and testable. The elements must be measurable and controllable. There are limits to the ability of science to answer questions. Consider the question: Do excessively high temperatures cause people to behave immorally? Can a scientist investigate this question? Temperature is certainly a well-defined, measurable, and controllable factor, but morality of behavior is not scientifically measurable. Thus, there is no experiment that can be performed to test the question.

Read the following questions and circle the number of each that could be answered scientifically.

1. Does watching television before the age of one contribute to the development of autism in children?
2. Did the use of the herbal supplement ephedra cause the death of the 18-year old soccer player?
3. Does global warming cause an increase in frequency and intensity of forest fires?
4. Do cactus spines reduce herbivory?
5. Should human embryonic stem cells be used to treat Parkinson's disease?

How did you decide which questions can be answered scientifically?

Formulating Hypotheses

As questions are asked, scientists attempt to answer them by proposing possible explanations. Those proposed explanations are called **hypotheses**. A hypothesis tentatively explains something observed. It proposes an answer to a question. Consider question 4, preceding. One hypothesis based on this question might be "Spines on cacti reduce herbivory". The hypothesis has suggested a possible explanation for the observed spines.

A scientifically useful hypothesis must be testable and falsifiable. To satisfy the requirement that a hypothesis be falsifiable, it must be possible that the test results do not support the explanation. In our example, if spines are removed from test cacti and the plants are not eaten by animals, then the hypothesis has been falsified. Even though the hypothesis can be falsified, it can never be proved true. The evidence from an investigation can only provide support for the hypothesis. In our example, if cacti without spines were eaten, the hypothesis has not been proved, but has been supported by the evidence. Other explanations still must be excluded, and new evidence from additional experiments and observations might falsify this hypothesis at a later date. Seldom does a single test provide results that clearly support or falsify a hypothesis. In most cases, the evidence serves to modify the hypothesis or the conditions of the experiment.

The test of a hypothesis may include experimentation, additional observations, or the synthesis of information from a variety of sources. Many scientific advances have relied on other procedures and information to test hypotheses. For example, James Watson and Francis Crick developed a model that was their hypothesis for the structure of DNA. Their model could only be supported if the accumulated data from a number of other scientists were consistent with the model. Actually, their first model (hypothesis) was falsified by the work of Rosalind Franklin. Their final model was tested and supported not only by the ongoing work of Franklin and Maurice Wilkins but also by research previously published by Erwin Chargaff and others. Watson and Crick won the Nobel Prize for their scientific work. They did not perform a controlled experiment in the laboratory but tested their powerful hypothesis through the use of existing evidence from other research. Methods other than experimentation are acceptable in testing hypotheses.

Most of the knowledge of biology has been derived through scientific investigations, has been thoroughly tested, and is supported by strong evidence. However, scientific knowledge is always subject to novel experiments and new technology, any aspect of which may result in modification of our ideas and a better understanding of biological phenomena. The structure of the cell membrane is an example of the self-correcting nature of science. Each model of the membrane has been modified as new results have negated one explanation and provided support for an alternative explanation.

Before scientific questions can be answered, they must first be converted to hypotheses, which can be tested. For each of the following questions, write an explanatory hypothesis. Recall that the hypothesis is a statement that explains the phenomenon you are interested in investigating.

1. Does cell phone usage reduce auditory function?

2. Do offspring of mothers who jog each day have a mental advantage over offspring of sedentary mothers?

✍ Check your Progress

Which of the following statements could be investigated using scientific procedures? Describe how each statement could be falsified and what factors are measurable and controllable.

1. The death of unborn horses on Kentucky farms is due to toxic fungi.

2. Crime rates increase during the full moon.

3. Positive emotions prolong life.

4. Exposure to low levels of pesticides increases the risk of developing Parkinson's disease.

5. Modern birds are closely related to dinosaurs.

Designing Experiments to Test Hypotheses

The most creative aspect of science is designing a test that will provide unambiguous evidence to falsify or support a hypothesis. Scientists often design, critique, and modify a variety of experiments and other tests before they commit the time and resources to perform a single experiment. In this exercise, you will follow the procedure for experimentally testing hypotheses, but it is important to remember that other methods, including observation and the synthesis of other sources of data, are acceptable in scientific investigations. An experiment involves defining variables, outlining a procedure, and determining controls to be used as the experiment is performed. Once the experiment is defined, the investigator predicts the outcome of the experiment based on the hypothesis.

You will use the following example of a scientific investigation to identify variables, controls and predictions. Read the following investigation and the sections that follow, filling in answers where appropriate.

Investigation of the Effect of Sulfur Dioxide on Soybean Reproduction

Agricultural scientists were concerned about the effect of air pollution, sulfur dioxide in particular, on soybean production in fields adjacent to coal-powered power plants. Based on initial investigations, they proposed that sulfur dioxide in high concentrations would reduce reproduction in soybeans. They designed an experiment to test this hypothesis (Figure 1.1). In this experiment, 48 soybean plants, just beginning to produce flowers, were divided into two groups, treatment and no treatment. The 24 treated plants were divided into four groups of 6. One group of 6 treated plants was placed in a fumigation chamber and exposed to 0.6 ppm (parts per million) of sulfur dioxide for 4 hours to simulate sulfur dioxide emissions from a power plant. The experiment was repeated on the remaining three treated groups. The no-treatment plants were divided similarly into four groups of 6. Each group in turn was placed in a second fumigation chamber and exposed to filtered air for 4 hours. Following the experiment, all plants were returned to the greenhouse. When the beans matured, the number of bean pods, the number of seeds per pod, and the weight of the pods were determined for each plant.

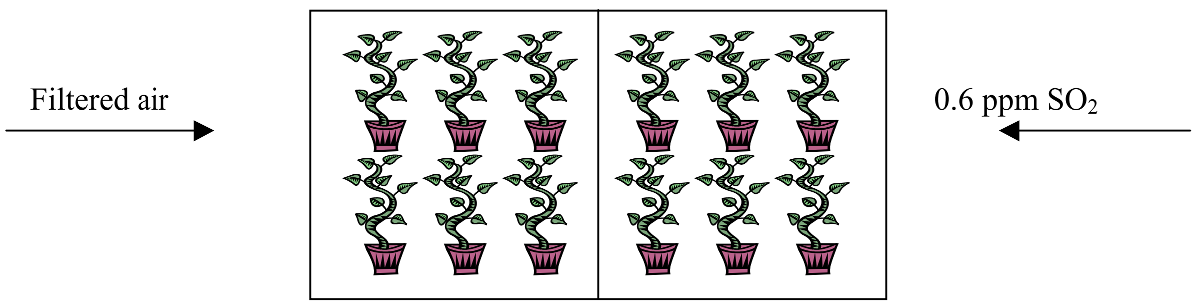

Figure 1.1 Experimental design for soybean experiment. The experiment was repeated four times. Soybeans were fumigated for 4 hours.

Determining the Variables

Read the description of each category of variable; then identify the variable described in the preceding investigation. The variables in an experiment must be clearly defined and measurable. The investigator will identify and define **dependent, independent,** and **controlled variables** for a particular experiment.

The Dependent Variable

Within the experiment, one variable will be measured or counted or observed in response to the experimental conditions. This variable is the dependent variable. For the soybeans, several dependent variables are measured, all of which provide information about reproduction. What are they?

The Independent Variable

The scientist will choose one variable, or experimental condition, to manipulate. This variable is considered the most important variable by which to test the investigator's hypothesis and is called the independent variable. What was the independent variable in the investigation of the effect of sulfur dioxide on soybean reproduction?

Can you suggest other variables that the investigator might have changed that would have had an effect on the dependent variables?

Although other factors, such as light, temperature, time, and fertilizer, might affect the dependent variables, only one independent variable is usually chosen. Why is it important to have only one independent variable?

The Controlled Variable

Consider the variables that you identified as alternative independent variables. Although they are not part of the hypothesis being tested in this investigation, they would have significant effects on the outcome of this experiment. These variables must, therefore, be kept constant during the course of the experiment. They are known as the controlled variables. The underlying assumption in experimental design is that the selected independent variable is the one affecting the dependent variable. This is only true if all other variables are controlled. What are the controlled variables in this experiment? What variables other than those you may have already listed can you now suggest?

Choosing or Designing the Procedure

The procedure is the stepwise method, or sequence of steps, to be performed for the experiment. It should be recorded in a laboratory notebook before initiating the experiment, and any exceptions or modifications should be noted during the experiment. The procedures may be designed from research published in scientific journals, through collaboration with colleagues in the lab or other institutions, or by means of one's own novel and creative ideas. The process of outlining the procedure includes determining control treatment(s), levels of treatments, and numbers of replications.

Level of Treatment

The value set for the independent variable is called the level of treatment. For this experiment, the value was determined based on previous research and preliminary measurements of sulfur dioxide emissions. The scientists may select a range of concentrations from no sulfur dioxide to an extremely high concentration. The levels should be based on knowledge of the system and the biological significance of the treatment level. In some experiments however, independent variables represent categories that do not have a level of treatment (for example, gender). What was the level of treatment in the soybean experiment?

Replication
Scientific investigations are not valid if the conclusions drawn from them are based on one experiment with one or two individuals. Generally, the same procedure will be repeated several times (replication), providing consistent results. Notice that scientists do not expect exactly the same results inasmuch as individuals and their responses will vary. Results from replicated experiments are usually averaged and may be further analyzed using statistical tests. Describe replication in the soybean experiment.

Control
The experimental design includes a control in which the independent variable is held at an established level or is omitted. The control or control treatment serves as a benchmark that allows the scientist to decide whether the predicted effect is really due to the independent variable. In the case of the soybean experiment, what was the control treatment?

What is the difference between the control and the controlled variables discussed previously?

Making Predictions
The investigator never begins an experiment without a prediction of its outcome. The prediction is always based on the particular experiment designed to test a specific hypothesis. Predictions are written in the form of if/then statements: "If the hypothesis is true, then the results of the experiment will be ... "; for example, "if cactus spines reduce herbivory, then removal of the spines will result in greater surface area removed by herbivores." Making a prediction provides a critical analysis of the experimental design. If the predictions are not clear, the procedure can be modified before beginning the experiment. For the soybean experiment, the hypothesis was: "Exposure to sulfur dioxide reduces reproduction." What should the prediction be? State your prediction.

To evaluate the results of the experiment, the investigator always returns to the prediction. If the results match the prediction, then the hypothesis is supported. If the results do not match the prediction, then the hypothesis is falsified. Either way, the scientist has increased knowledge of the process being studied. Many times the falsification of a hypothesis can provide more information than confirmation, since the ideas and data must be critically evaluated in light of new information. In the soybean experiment, the scientist may learn that the prediction is true (sulfur dioxide does reduce reproduction at the concentration tested). As a next step, the scientist may now wish to identify the particular level at which the effect is first demonstrated.

Recall the previous numbered list of hypotheses. Consider how you might design an experiment to test the first hypothesis. For example, you might measure auditory function by performing hearing tests or observing changes in structures in the ear. The prediction might be:

> If cell phone usage reduces auditory function (a restatement of the hypothesis), then people who use cell phones will score lower on hearing tests than persons who do not (predicting the results from the experiment).

Now consider an experiment you might design to test the second hypothesis from the list. How will you measure "mental advantage"? State a prediction for this hypothesis and experiment using the if/then format:

The actual test of the prediction is one of the great moments in research. No matter the results, the scientist is not just following a procedure but truly testing a creative explanation derived from an interesting question.