LABORATORY

Science—A Process

I

OVERVIEW

Science is a way of examining and finding order in the natural world. It is a dynamic process of asking questions and then seeking answers. Observations lead us to formulate questions and, with our limited knowledge, we may offer tentative explanations or make educated guesses about the answers to our questions.

Scientists call a tentative explanation a **hypothesis.** Experimentation follows, providing information that may support or refute a hypothesis. From data, often reinforced by statistics, conclusions can be made about what it is we wish to know.

In this laboratory, you will investigate reaction time—the length of time it takes to react to a stimulus. If available, a computer-generated reaction time program will be used. A less complex series of tests can be conducted without the use of a computer. By formulating hypotheses, designing experiments, and analyzing data, you will engage in the process of science.

> **Please Note:** During your laboratory course, you will often be required to formulate hypotheses and design investigations in the Procedure section of an exercise. You will also have the opportunity to design your own experiments to apply what you have learned. These experiments are designated as Extending Your Investigation. Some of these are designed as class experiments; others are intended to be carried out at home.

Laboratory I provides you with the basic tools to carry out scientific investigations and the statistical tools to evaluate your results.

STUDENT PREPARATION

Before coming to the laboratory, complete Exercise A and steps 1 and 2 of Exercise F.

EXERCISE A The Scientific Method

The scientific approach is a powerful method for understanding the natural world because it is based on observations of how the world works. However, not just any observations will do: the observations must be systematic and objective. The method for making these observations is sometimes broken down into a series of steps referred to as the **scientific method.**

The scientific method of inquiry is an important part of everything we do in our daily lives; we simply do not recognize the steps because we are so used to them. Scientific inquiry involves the steps outlined below.

Problem You want to find out whether a combination of anti-cholesterol drugs X and Y is more effective in reducing high cholesterol levels than either of the drugs given separately. You might proceed as follows.

Step 1 Make **observations** that lead to the formulation of a question.

You observe that drugs X and Y, used independently, lower LDL (low-density lipoprotein) levels in the blood. You question whether drug X plus drug Y, given in combination, would be even more effective.

Step 2 The question leads to a tentative explanation or educated guess—a **hypothesis.** Prior knowledge or research or even intuition can contribute to the formulation of a hypothesis. The hypothesis must be tested in a way *that allows it to be proven false.* We can never prove that a hypothesis is true, but we can support the hypothesis if repeated experiments do not falsify it.

You formulate the following hypothesis: If individuals with high cholesterol levels are treated with a combination of drugs X and Y, their cholesterol levels will be lowered more than for similar groups treated with drug X alone or drug Y alone.

For statistical reasons (to be covered later), you also devise a **null hypothesis** or prediction of what would happen if the experimental treatment has *no* effect.

The null hypothesis is that cholesterol will be lowered by the same amount with all three drug treatments.

Step 3 Make **predictions** about the results you would expect if the hypothesis is correct. In this way, scientists begin to formulate an experimental design. Hypotheses are often stated in the form of predictions.

You predict that treating individuals with drugs X and Y in combination will be more effective than treatment with either drug alone. As part of your experimental design, you know that you will need to compare at least three experimental groups, and you may begin to plan how to identify participants for your study.

Step 4 Clearly define the experiment's independent, dependent, and standardized **variables.** The **independent variable** is the factor that is being manipulated in the current experiment.

The independent variable is the type of drug treatment. (In the experiments you will be performing in this laboratory, you will usually deal with only one independent variable at a time.)

The dependent variable is the aspect of the system that is showing some response to the manipulations of the independent variable.

The dependent variable could be any of the many aspects of an individual's condition that define the difference between life-threatening high cholesterol levels and lower levels typical of healthy individuals.

The **standardized variables,** or **controlled variables,** are all the variables that are held constant between the treatments.

The way the drugs or drug mixture are administered, the frequency with which the subjects are checked, and the average ages and general health characteristics of the individuals assigned to the treatments are all standardized variables.

Step 5 Define the **experimental treatments.** A treatment is a test group of individuals that are subjected to the same levels of the independent variable.

The group that gets drug X alone is one treatment, the group that gets drug Y alone is another treatment, and the group that gets both drug X and drug Y is the third treatment.

Step 6 Select materials and identify experimental methods and methods of data collection and analysis, as part of a well-planned **experimental design.** These are incorporated into a **procedure** that tests whether the predicted results occur.

You identify a large group of individuals who have high cholesterol levels but are otherwise healthy. You randomly assign them to groups that will get drug X alone, drug Y alone, and drugs X and Y. You make sure that all the treatments have a fair chance against one another by ensuring that they all have subjects with a similar range of ages, health, previous treatment histories, and so forth. If you do not do this and one treatment ends up with most of the younger, healthier patients and the other with most of the older, sicker ones, it will be impossible to say whether the results of the experiment are due to the drugs or to the biased selection of people entering each treatment.

The experiment should also have a fourth **control treatment.**

In the control group, individuals with high cholesterol get *no* drug treatment but are given placebos and are held to the same standardized variables.

Step 7 Perform experiments and collect data.

You make sure that all participants who will be taking the drugs understand the drug dosages and administration conditions that the experiment demands, that the subjects are checked frequently, and that all medical personnel are using the same definition of high cholesterol. You should pre-plan procedures for dealing with inevitable problems such as patients who miss drug treatments or drop out of the program.

Step 8 Analyze **results** (data) from the experiments that test the hypothesis, using statistics when necessary, and interpret these results to determine whether the hypothesis is supported or falsified. This leads to a **conclusion.**

Step 2 included the statement of a null hypothesis, or prediction of what would happen if no treatment effect occurred. While the null hypothesis may seem negative and uninteresting, it is important because most statistical techniques can only test a null hypothesis. Therefore, you will probably end up concluding either that **the data allowed us to reject the null hypothesis** (meaning that there was a treatment effect), or that **the data did not allow us to reject the null hypothesis** (meaning that there was no evidence of a treatment effect). You *cannot* say, "We proved there was an effect" or "We proved there was no effect." Although it is common to talk about "experimental proof," experiments do not *prove* anything. **Experiments can only offer evidence that either supports, or fails to support, hypotheses.**

Step 9 Repeat the process, using a more refined question about the system.

Assume that the combination of drugs was more effective than either drug taken individually. Next, you might ask if the best results are obtained when the two drugs are given in equal or in unequal amounts. Or, you might ask if a combination of drugs X, Y, and Z is more effective than a combination of just X and Y.

The usual result of an experiment is more questions.

Objectives

- ☐ Recognize the stages of scientific inquiry as it applies to everyday experiences.
- ☐ Make observations, formulate hypotheses, make predictions, and design experiments to test hypotheses.

Procedure

You have just received a grade on your first major examination in biology, and it is not as high as you had hoped. You wanted an "A" and you earned a "C." You talk to your professor and do a lot of thinking about what might have gone wrong. Perhaps your mistake was reviewing your notes only before the exam rather than every night. Or perhaps you made some other mistakes.

1. Using this scenario, apply the steps of the scientific method to identify what you might do to raise your grade on the next exam.

Step 1 Make observations that lead to a question. _____

_____

Step 2 Formulate a hypothesis. _____

_____

Step 3 Make predictions based on this hypothesis. _____

_____

Step 4 Define the independent and dependent variables. _____

_____

Step 5 Define the experimental treatments. _____

_____

Step 6 Design your experiment. _____

_____

Step 7 Perform the experiment and collect data. _____

_____

Step 8 Analyze your data. _____

_____

Step 9 Plan a more refined experiment. _____

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2. Now, suppose your grade on the next examination remains low. *How could this cause you to revise your conclusions about your original hypothesis?* _____

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EXERCISE B Reaction Time Experiments: Making Observations

One of the basic features of life is that living things react to stimuli from the environment. This may be as obvious as a frog hopping away as you approach, or as subtle as a plant changing its pattern of hormone secretion in response to increasing day length in the spring.

Reaction time is the length of time it takes to begin a response to a stimulus. Any number of stimuli can evoke specific responses. For instance, seeing movement out of the corner of your eye could cause you to turn your head. Another example might be slamming on the brakes when an animal runs out in front of your car. From your normal day-to-day life, list some stimuli and their associated, observed responses. Be careful not to extend your observations into inferences (*inferences* are explanations or interpretations of observations).

In this experiment, you will use a computer program to test your reaction time. The program presents a stimulus and then uses the computer's internal clock to measure the time it takes you to respond to the

Stimulus	Observed Response

stimulus by pressing the spacebar. If the computer program is not available, you will test your ability to catch a ruler dropped between two of your fingers—can you react fast enough to catch it?

Objectives

- ☐ Make observations about responses to stimuli.
- ☐ Make observations about differences in reaction times.

Note: If you are *not* using a computer for this exercise, skip to Exercise B, Part 2.

PART I Making Observations (*for Laboratories Using Computers*)

Procedure

1. Your instructor will provide you with directions for loading the reaction time program.
2. After starting the program, choose *Collect some reaction time data.*
3. Choose *Use just the reaction time program.*
4. The reaction time program will present you with a stimulus and then ask you to respond by pressing the spacebar. The stimuli can be either visual or auditory, and simple or complex. Possible reaction time tests include:
   - **X at a known location** An "X" appears in the middle of the screen.
   - **Spot the dot** A period appears somewhere on the screen. The period may be either high-contrast (white on a blue background) or low-contrast (black on a blue background). The dot may appear on a small area of the screen or anywhere on the whole screen.
   - **Symbol recognition** You are given a list of 1 to 10 letters. Then letters appear in the middle of the screen and you press the spacebar *only* if the letter is on your list. For example, if your list is "A G B," you press the spacebar if you see an A, or G, or a B, but *not* if you see any other letter.
   - **Reaction to sound** The computer sounds a tone.
   - **Tone recognition** The computer sounds either a low tone or a high tone. You press the spacebar only if the *high* tone sounds.
5. Take some time to become familiar with what each test requires.
6. In the space below, record observations about your reaction time on the different tests, possible environmental effects on your reaction time, or differences in reaction times among individuals.

These observations will serve as information for formulating a hypothesis. You will work in a laboratory group of eight (four pairs), so share your observations with others in your laboratory group. Once you are familiar with the program, you and the other members of your lab group will devise a reaction time hypothesis (Exercise C) and an experiment to test your hypothesis (Exercise D). You will then collect and analyze your data (Exercises E–G).

PART 2 Making Observations (*for Laboratories Not Using Computers*)

Procedure

1. Work in pairs. Place a ruler (preferably stainless steel) in the crevice formed by the second (index) and third fingers of your partner's preferred hand (right, if right-handed; left, if left-handed). Orient the ruler so that the 1-cm mark is downward (Figure IB-1). Now ask your partner to open the two fingers as wide as possible.
2. Drop the ruler. When caught, record the millimeter marking at the top surface of the fingers.

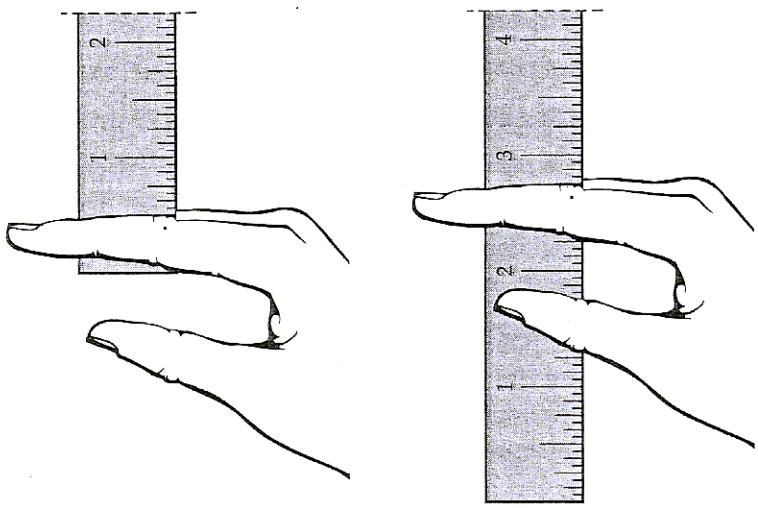

Figure IB-1 *Positioning of ruler for reaction time experiment.*

3. Try this technique several times. Make sure that the original position of the ruler, before dropping (step 2), is the same each time. In the space below, record observations about the mechanics and "times" of reactions (measured as number of millimeters) for different partners. Are there any environmental or individual differences that might be affecting reaction times?

These observations will serve as information for formulating a hypothesis. You will work in a laboratory group of eight (four pairs), so share your observations with others at your laboratory table. Once you are familiar with the mechanics of the exercise, you and the other members of your lab team will devise a reaction time hypothesis (Exercise C) and an experiment to test your hypothesis (Exercise D). You will then collect and analyze your data (Exercises E–G).

EXERCISE C The Reaction Time Experiments: Formulating a Hypothesis

Use of our general and perhaps nonsystematic observations often leads to devising a question about the observed system. A **hypothesis** is a question, often stated in the form of an educated guess or possible answer (tentative explanation) to a question. Hypotheses lead to predictions—indeed, hypotheses are often stated as predictions. Two additional criteria must be met by a hypothesis: