INVESTIGATIONS IN BIOLOGY

The best way to learn biology is to *do* biology. There are many ways to do this. For example, throughout this manual you'll find *directed labs* that use traditional skills and activities (e.g., how to use a microscope) to immerse you in the process of biology. Similarly, *thematic labs* will involve you in discovering the themes of biology (e.g., evolution, ecology). These activities will help you experience the biology you have learned from lectures, your textbook, and this manual.

We also want you to design your own experiments so that you can learn biology *your* way. These activities, which are part of every lab, are *investigative labs*. Some of these investigations are independent activities, whereas others are extensions of topics studied in directed labs and thematic labs. In investigative labs, you'll apply the skills you've learned to answer your own questions about biology. In doing so, you'll be challenged to create and develop *your* way of answering scientific questions.

Investigations in biology often go far beyond simply following the steps of the scientific method. Indeed, investigation is a broad pursuit that includes observations, experiments, analysis of the work of others, reliable procedures, and repetition. It's more of an approach to answering questions than it is a set of rigid procedures. Although investigation doesn't have to be complicated, it does require creativity, planning, patience, and attention to detail.

Investigations proceed along a variety of paths, depending on the investigator and the question being asked. But the steps we've described below can improve any investigation, including those suggested in this lab manual.

Establish a clear question. Investigations begin with observations and questions. Simple, straightforward questions are usually the best. When you've decided on your question, *write it down*. You will be surprised how much easier it is to recall and refine a written question than it is to develop a vague idea rattling around in your head. Make sure your question is stated clearly. And here's a tip for asking productive questions: Learn as much as you can about what you're proposing to do. The more background information you have, the better your questions will be, and the more likely your results will make sense.

Not all questions require controlled experiments. For example, some investigations are descriptive rather than experimental. Decide whether your question is best answered with experiments in controlled systems or with observations in natural systems. You may investigate the impact of pollutants

by administering them to controlled organisms, or you may choose to describe observations about a pollutant's effects in a natural community. Both approaches can lead to interesting and important results.

Design a reliable experiment. Outline what you are going to do, and write down the steps of your procedure in numerical order. The most reliable experiments are usually the simplest ones. Complicated procedures are often hard to repeat and are prone to error. Remember that a hallmark of good science is that it's repeatable. To keep things simple and repeatable it's best—whenever you can—to isolate a single variable and hold all other conditions constant. That way you can easily repeat your experiment and refine your ability to reliably measure the most important variable.

Simple, reliable procedures also make it easier to establish appropriate controls. If all conditions surrounding your experiment except one variable are held constant, then it is relatively easy to design a good control. A good control is a replicate procedure with the variable of interest either held constant or absent. For example, if you want to detect the effects of a pollutant on plant growth, then you need a control with the same growth conditions as the pollutant treatments, but without the pollutant you are studying.

Another good tip for designing successful investigations is to use readily available organisms and materials for procedures. Good science does not have to be complicated with expensive equipment or exotic organisms. There is no need to use a rat if a fruit fly will do.

If the experiment you're proposing requires materials other than the ones provided, ask your instructor if those materials are available. Also, get input from other people about your proposed work—investing time *before* you do the work can save much time later.

Work objectively. Decide beforehand what result will validate your hypothesis and answer your question, and what result will invalidate your hypothesis. If possible, use tables and graphs to show your results. Write down not just your data, but also what your data mean. Try not to think about what your results *should be*. Instead, accept what they *are*. Some of the most interesting results are those that we didn't predict, for unexpected results often lead to more questions. And that's a good thing!

Strengthen your conclusions. The best way to strengthen your conclusions is to repeat your work. Along with repetition, conclusions are stronger when they are supported by different kinds of evidence. For example, if you are investigating the effects of a nutrient on plant growth, then your conclusion is stronger if you investigated more than one species of plant. Similarly, conclusions based on highly controlled laboratory experiments are strengthened by corroborative data on plant growth in natural communities with various levels of that nutrient.

Be prepared to revise your questions and experimental design. You'd be surprised how many initial experiments in an investigation "don't work." The results make no sense, or you can't measure the variable you thought you were going to measure with the precision you expected. Or, the first experiment gives one result and the second experiment gives another. If this happens, do not be overly concerned—this is precisely how "real science" goes. Think about what might be the problem; perhaps it's arising from some source of variation in one replicate that's not in the other replicates. The cure for that problem is revision and repetition. It's worth saying again … good science is reliable and repeatable.

Figure out what your data mean. Discuss your data in light of your original question or hypothesis. Do your results support or falsify your hypothesis? Use your data to explain your reasoning. What is the significance of your work? That is, what can you conclude from your investigation? Are there other interpretations from results? How do your results compare with those of others? Based on what you've learned, can you now ask different or more probing questions to learn even more? Remember that correlation does not necessarily indicate cause and effect. If you had problems with your investigation, discuss how these problems might have been avoided. If you could repeat or revise your work, what would you do differently?

Be prepared to report your work. Scientists often remark that "you haven't done science until you have published your work." Lab write-ups are the beginning of a publication. The topics discussed in "How to Write a Scientific Paper or Laboratory Report" (pp. xxi–xxiii) will help prepare you to present your ideas to others.