A LABORATORY GUIDE TO THE NATURAL WORLD

Dennis J. Richardson and Kristen E. Richardson

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Prentice Hall

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For Katherine, Marjorie, and Emma
Our favorite little varmints

Preface

We often hear the argument that non-majors students shouldn't have to learn much about biology because it seems unimportant in the real world. Yet, we humans are animals – linked to all other life on this planet, governed by the same natural laws as everything else. A biology laboratory course gives you a better understanding of yourself and reveals your relationship to all other living organisms. And as we face increasing disease outbreaks, energy crises, and environmental mismanagement, an understanding of biology has never been more important.

And so we present *A Laboratory Guide to the Natural World*. The exercises in this guide are built upon the solid foundation of a traditional approach, while infusing an inquiry-based component that allows you to explore the natural world within the confines of tried-and-true learning experiences. These exercises encompass many levels of biological organization, with a touch of aesthetic and philosophical aspects of natural history. We hope you will walk away with a new understanding of the natural world around you, a world of wonder and beauty. It is our sincere desire that your study of biology will be both pleasant and educational in the truest sense.

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We are especially grateful for our children, who have tolerated us while growing up with this project. And yes, Kate, it will be done by the time you turn 7.

D.J.R. and K.E.R.

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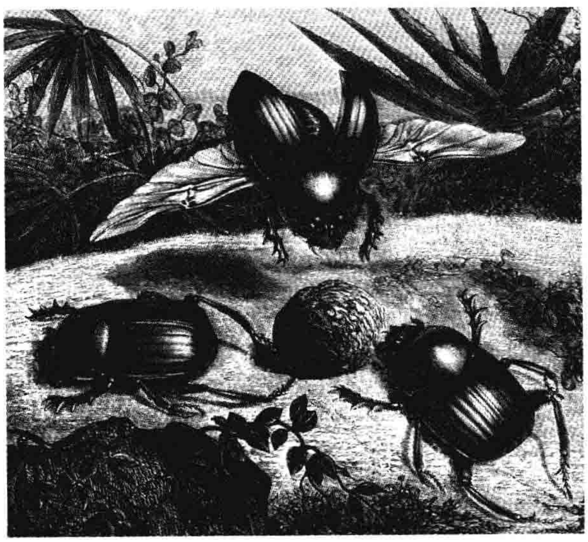

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Science as a Way of Learning

We start off confused and end up confused on a higher level.
A. F. Chalmers, 1976

Here you are, in a biology course that you've put off as long as possible. Does the word *science* give you an uneasy feeling? Science can be overwhelmingly complex, but learning about it doesn't have to be. A famous scientist once said that science is "nothing but trained and organized common sense" *(Huxley, 1854)*. Take it one step at a time, and you will see how the pieces fit together.

Start by observing something about the living world around you. You may notice a vine-like morning glory climbing on a fence, for example (Figure 1.1). Then ask a question. Why do the flowers of a morning glory bloom (open) only for a few hours each day? By asking a question, you are already on your way to understanding biology. You may not realize how many steps you take just to ask a question: you look at the plant on several occasions, and you observe how the flowers are open in the morning, but closed later in the day.

Why do they bloom only for a few hours? The steps you take to answer the question will flow in a logical manner. You think of some factors that may affect blooming. Do the flowers open only on sunny days? Does blooming depend on the temperature? Does humidity play a part in blooming? You decide to answer your question by investigat-

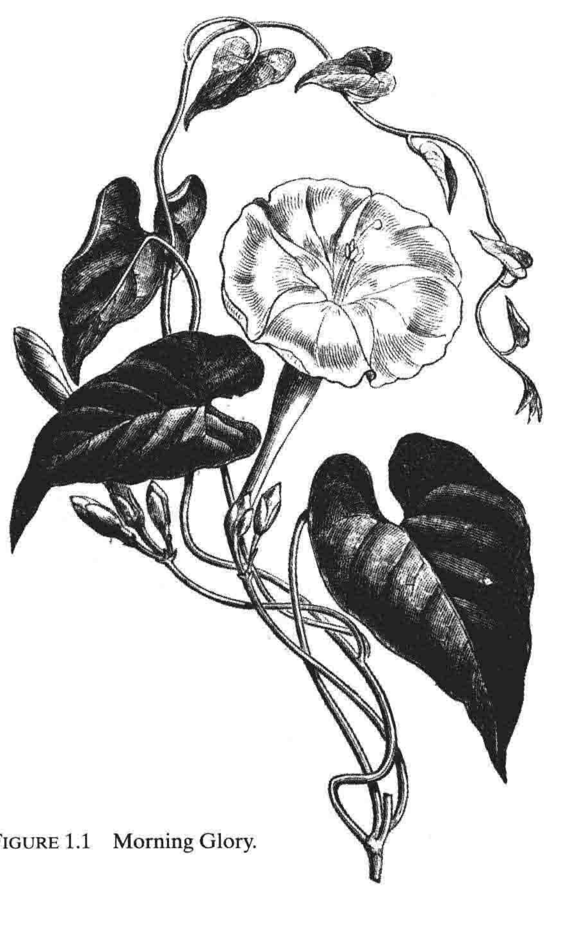

FIGURE 1.1 Morning Glory.

ing one of the possibilities. If blooming is temperature-dependent, then the flowers should open as the temperature climbs, and close as higher temperature approaches.

After observing the flowers for a few days, you may see a pattern that is consistent with the temperature-dependent approach. Or you may see a pattern that isn't. In either case, you could start the investigation over to learn additional information. If the flowers bloom in a temperature-dependent manner, then you can investigate why they might do so. Or if temperature doesn't seem to have an effect on blooming, then you can eliminate that possibility and investigate another.

In this manner, we do indeed start off confused (with a question) and end up confused (with another question) on a higher level! Much of biology is discovered with this approach, called the **scientific method [Krogh section 1.3]**. As you can see, it is only organized common sense, but it can lead to fascinating knowledge.

THE SCIENTIFIC METHOD

The example just presented fits into the steps of the scientific method.

1. **Observation** You observe that *morning glory blooms only during certain hours of the day.* In many experiments, this step includes personal observation as well as reading what is already published. Such pieces of information are sometimes referred to as *facts*.
   In science, *fact* refers to a piece of information; this is unlike the vernacular (every day) use, where *fact* refers to a statement of truth, or something that is undeniable.
2. **Question** The question that follows is *Why do the blooms close at midday?*
3. **Hypothesis** A hypothesis is a tentative, general statement based on specific observations. You have several hypotheses: *Sunlight affects blooming. Temperature affects blooming. Humidity affects blooming.*
4. **Prediction** Predictions are logical conclusions to be expected in view of the hypothesis. They may be phrased in the form of an if-then statement: If the hypothesis is correct, then a certain outcome is expected. Predictions provide opportunities to find independent pieces of evidence supporting a hypothesis, as well as opportunities to reject a faulty hypothesis. Based on the temperature hypothesis, this prediction follows: *If blooming is temperature dependent, then the flowers should open as the temperature climbs and close as higher temperature approaches.*
5. **Experiments** Predictions are tested by observation and/or experimentation. If you conduct your experiment over a few days, you may find that *blooming is temperature dependent*. Or you may not.
6. **Conclusion** New data is the product of observation and experimentation. *The new data will either support or fail to support the hypothesis. Datum* is singular, and *data* is plural.

A hypothesis can never be proven. To claim that you have proven a hypothesis is to claim that you have a hold on absolute truth. Within the conceptual boundaries of science, absolute truth is unattainable. This is not to say that absolute truth does not exist, just that it can never be known in regard to science. It is most appropriate for a scientist to use terms like *data* rather than *facts* and *principles* rather than *truths*. It is better for a scientist to say that data *suggest* than to say that data *prove* something.

Why is a scientific discovery not "absolute truth"? There are several reasons. One is because hypotheses are based on observations and data from a particular point in time. We are continuously learning more about the world around us, and sometimes new information pushes old conclusions aside. You may say "Eureka! I have proven that blooming in morning glories is temperature dependent!" But you'll be scratching your head if someone else finds that the flowers bloom even in colder (yet very sunny) weather next week. And so, you'll have to show your objectivity, step aside, and consider their findings.

Once a hypothesis has amassed a great amount of supporting evidence, it may be afforded the status of theory. A **theory** is a general set of principles that explain some aspect of nature. Note that a theory is *not* a hypothesis that has been proven. It is a hypothesis with a tremendous amount of supporting evidence.

In scientific use, a *theory* is a widely accepted paradigm, or model, that is supported by a tremendous amount of evidence. In vernacular use, *theory* refers to an idea, often with no more validity than a guess.

Exercise 1.1 EXPERIMENTAL DESIGN

In designing an experiment several variables are defined:

The **independent variable** is the variable that is manipulated. *You manipulate the temperature of the plant's atmosphere.*

The **dependent variable** is the variable that will be measured. *You measure plant blooming, noticing the temperature at which the plant blooms.*

Controlled variables are kept constant throughout the experiment. *The soil type, amount of water applied, and amount of light are kept constant.*

The **experimental group** contains plants that are subjected to manipulation. *Morning glory plants in this group will be subjected to rising temperature.*

The **control group** contains standard conditions, in which the independent variable is not manipulated. The control group usually approximates "normal" conditions. However, these plants should be grown in the lab, to eliminate effects of humidity and plant growth, variables we do not want in this experiment. *Morning glory plants in this group will be exposed to constant temperature.*

Read this very carefully: When comparing the experimental group to the control group, the effects of the independent variable can be determined by measuring the dependent variable in both groups. *You compare blooming in the experimental group to blooming in the control group. Does temperature appear to have an effect on blooming? If yes, then the data support the hypothesis. If not, then the hypothesis is rejected.*

When scientists compare experimental to control groups, they do so using statistical analysis, which are mathematical tests to determine whether observed differences in the two groups are "real" or are a result of "pure chance." When a scientist claims that something is significantly different from something else, she is implying that the differences are real according to statistical analysis.

After reading the following example, identify the components of its experimental design.

Farmer Hen read an article in *Sodbuster* magazine that some researchers "down at the U" had developed a new fertilizer called *Big Red Fertilizer*. The product was supposed to be nothing short of an agricultural miracle. It produced corn plants that had more ears per plant. The article even claimed that kids who ate the corn grown with *Big Red Fertilizer* would turn into star athletes.

Based on what he read and what he had heard, Farmer Hen generated the hypothesis that *Big Red Fertilizer enhances corn production better than regular fertilizer*. From this hypothesis, Farmer Hen predicted that *if Big Red Fertilizer enhances corn production better than regular fertilizer, then corn plants raised on Big Red Fertilizer will have more ears of corn per plant than corn raised on regular fertilizer*. He designed an experiment to test the prediction as follows: Corn was planted at the same time in two adjacent fields. One field was fertilized with *Big Red Fertilizer* and the other received regular fertilizer. The fields were plowed on the same days and were irrigated, receiving equal amounts of water on the same days.

At the end of the season, Farmer Hen observed the corn plants and found that plants maintained on *Big Red Fertilizer* indeed had more ears than those that had received regular fertilizer. Thus his prediction was found to be correct, and the hypothesis that *Big Red Fertilizer* enhances corn production better than regular fertilizer was supported. Note that although the hypothesis was supported, it was not *proven* to be correct!

Questions

1. **What is the hypothesis?**

2. **What is the prediction?**

3. Which plants are included in the experimental group?

4. Which plants are included in the control group?

5. Identify the independent variable.

6. Identify the dependent variable.

7. Identify the controlled variables.

8. What conclusion would be drawn if the corn plants in the control field were found to have more ears of corn per plant than plants from the experimental field?

9. What conclusion would be drawn if the corn plants in the control field were found to be taller than plants from the experimental field?

10. What other prediction(s) might be generated from the hypothesis in the preceding example?

Exercise 1.2 A LIBRARY EXERCISE IN THE SCIENTIFIC METHOD

Another step in the scientific method is publication of the findings. Findings are of no value unless they are communicated throughout the scientific community! Results of scientific investigation are sometimes reported in journals maintained by professional scientific societies. Examples of these include *Journal of Protozoology, American Journal of Botany*, and *American Midland Naturalist.* Table 1.1 gives the common parts of a scientific paper and describes the purpose for each section.

The vast majority of good experiments follow the scientific method, even if the hypothesis and prediction(s) are not explicitly stated. You will be assigned a scientific paper from a professional