very different goals, so look for those that can best inform you at your own level of understanding and interest.

Some scientific knowledge is highly technical. As a result, scientists have a tendency to speak on a technical level and primarily to each other. As we’ve already mentioned, scientists often communicate by means of articles in specialized peer-reviewed journals such as Nature and Science. Articles in peer-reviewed journals are concise, accurate, and documented so thoroughly that another scientist ought to be able to duplicate the work after reading the article. Generally they refer extensively to previous literature on the subject. Articles in peer-reviewed journals make for abhorrent reading, and they are usually as dry as toast. But bear in mind that their purpose is primarily to inform other experts.

Other helpful print sources are science magazines and nonfiction books meant for the well-educated public. The goal is to inform the interested reader who may have only a limited background in science. The authors are usually science writers or experts who translate the finer scientific points into language that we can all understand. The information is generally accurate and readable, although the reader may not understand some of the details. Generally these articles and books tell readers who want to delve more deeply into the subject where to find more information.

General interest news magazines and daily newspapers also report on selected hot topics in science. Their goal is to get the information out as quickly as possible to a wide audience. Coverage is timely but less in-depth than in science magazines, and may not include the details you need to check the validity of the statements. A decided plus is that magazines and newspapers often discuss social, political, economic, legal, or ethical ramifications of the scientific findings, something generally lacking in the previous sources. Although the scientific information is usually accurate, the reporter may not understand the subject fully and may not provide adequate context. The best articles point the reader to the original sources. Television (for instance, the Discovery Channel, Nova) also presents science-related topics to the public.

Since the 1980s, scientists and researchers have used the Internet to communicate and share ideas. The recent expansion of the World Wide Web has made the Internet accessible to the general public, opening exciting new sources of scientific information. Nearly all universities now have Web pages; the site addresses end in “edu” (for “educational”) rather than “.com” (for “commercial”). A number of scientific and professional organizations have created Web sites that offer helpful information for both scientists and consumers. Examples of organizations with Web sites include the National Institutes of Health, the American Cancer Society, and the American Heart Association. The Web addresses of government agencies and non-profit organizations generally end in “gov” and “.org,” respectively.

Be aware that the Internet can also be a source of misinformation. At present the Internet is less closely regulated than print and broadcast media, so it can be difficult to tell the difference between objective reports and advertisements. In addition, participants in online chat rooms and special interest groups may promote their own opinions as proven truths. It pays to be skeptical.

Recap The best sources of scientific information translate difficult or complex information accurately into understandable terms and have enough references that you can check the information if you wish.

1.5 Learning to be a critical thinker

Many scientists are motivated by strong curiosity or a sense of wonder and awe about how the natural world works. Exploring the frontiers of knowledge requires a great deal of creativity and imagination. Like many people, however, scientists may leap to conclusions or resist new ideas. A few may be driven by self-interest. To combat these natural human tendencies, good scientists try to use certain tools of critical thinking. You too can learn to use these tools, regardless of whether you choose a career in science.

The sections below describe some of the simple tools that anyone can use to improve their critical thinking skills.

Become a skeptic

Good scientists combine creativity and imagination with skepticism, a questioning attitude. If you’ve ever bought something based on claims about how well it works and then been disappointed, you know the value of skepticism. Question everything and dig a little deeper before believing something you read and hear. Here are some questions you might ask yourself:

- Who says that a particular statement is true?
- What evidence is presented?
- Are the persons speaking on a subject qualified by training or skill to speak authoritatively about it?
- Are they being paid, and if so, how might that affect what they have to say?
- Where’s the evidence to back up a claim?

Skepticism is particularly important for claims that are new, startling, and not yet verified by other scientists. Listen carefully to the debate between scientists in the public arena. A new scientific claim may take several years to be checked out adequately.

Appreciate the value of statistics

Statistics is the mathematics of organizing and interpreting numerical information, or data. Scientists use statistics to determine how much confidence they should place in
information. Most scientists would be willing to accept experimental results with confidence if (according to statistical tests) they would get the same outcome 19 of every 20 times they repeat the experiment, or 95% of the time. When you see numerical averages followed by a smaller "±" number, the smaller number represents an expression of confidence in the certainty of the results, called the "standard error." In graphs, the standard errors are represented as small lines that extend above and below the average number.

Statistics are important in many disciplines. During elections, we may hear pollsters report, for example, that "52% of the respondents said that they will vote for the president. The poll has a margin for error of ±3%." This tells you the pollsters are relatively certain that the actual percentage who will vote for the president is somewhere between 49 and 55% still too close to call.

Learn how to read graphs

Just like a picture, a graph is worth a thousand words. Graphs display data obtained from observations and experimental results in a way that is economical and easy to grasp. Graphs can also be used to clarify the meaning of experimental results.

Most graphs are plotted on two lines, or axes (singular: axis). The horizontal axis at the bottom is called the abscissa (from math you may know this as the x-axis), and the vertical axis is called the ordinate (y-axis). By convention the independent variable, such as time, distance, age, or another category that defines groups, is generally plotted on the abscissa. The dependent variable, so called because its variation may depend on the independent variable, is plotted on the ordinate.

Graphs can take a variety of forms, from plots of individual data points to lines or bars of average value (Figure 1.10). When reading a graph, first check the scales and the legends on the abscissa and the ordinate to determine what the graph is about. Be careful to look for a "split axis," in which the scale changes. An example is shown in Figure 1.11. A split axis is sometimes a convenient way of representing data that cover a wide range on one axis, but it can also be used to deliberately mislead people unfamiliar with reading graphs.

Distinguish anecdotes from scientific evidence

Anecdotal evidence takes the form of a testimonial or short unverified report. Although an anecdote may be true as stated, it in no way implies scientific or statistical certainty. It cannot be generalized to the larger population because it is not based on empirical evidence. Advertising agencies sometimes use anecdotes to influence you. The actor on television who looks sincerely into the camera and says "Drug X worked for me" may be telling the truth—the drug may work for him. But this does not prove the drug will work for everyone or even for 10% of the population.

Nonscientists (and even scientists) often say things like "My grandmother swears by this remedy." Again, the statement may be true, but it is not scientific evidence. Listen carefully to how the evidence for a statement is presented.

**Critical Thinking**: Suppose one brand of cold medication has personal testimonials on its Web site from three different people who all say that the medication helped them get over colds faster, while another brand has similar stories from 30 people. Does this prove that the second medication is better than the first? Why or why not?

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Figure 1.10 Types of graphs. Each of these graphs reports the relationship between freshman enrollment and total student enrollment at approximately 1,500 U.S. colleges and universities.

In the bar graph, why are the standard error bars in the third bar much higher than in the first bar? Put another way, what do standard error bars actually tell us? (Look back at the first graph for a hint.)
Separate facts from conclusions

A fact is a verifiable piece of information, whereas a conclusion is a judgment based on the facts. The news media often mix facts with conclusions without indicating which is which. Almost every evening on the business news we hear statements like “The Dow Jones Industrial Average declined 50 points today on renewed concerns over the consumer price index.” The first half of the sentence (about the decline) is a verifiable fact. The second half is conjecture on the part of the reporter.

Or consider the following: “The average global temperature was 0.1°C higher this year than last year. The rise in temperature proves that global warming is occurring.” Again, fact is followed by conclusion. The conclusion may not be warranted if temperature fluctuations up and down of 0.3°C are normal from year to year.

Understand the difference between correlation and causation

A close pattern or relationship (a correlation) between two variables does not necessarily mean that one causes the other. The catch-phrase is “correlation does not imply causation.” A good example of a correlation without causation is the close correlation between ice cream sales and drowning—when ice cream sales are up in the summer months, so are drownings. Does that mean that eating ice cream causes people to drown? Hardly. Ice cream sales and drownings also correlate with (and are most likely caused by) a third

Figure 1.11 How a split axis affects a graph. The graph in b) is redrawn from the data in a) by splitting the abscissa and omitting the data for the years 1920–1950. The effect is a consolidated graph that fits in less space, but it might mislead you into thinking that the number of cases of the disease has been rising steadily since 1910, instead of only since 1960.
factor not mentioned in the original correlation—warmer temperatures during the summer.

If the above example seems too obvious, try this one: In 1999 a study at a major university found that children who slept with a light on were more likely to develop nearsightedness (myopia) later in life. But does this mean that sleeping with a light on causes nearsightedness? In fact, a follow-up study in 2000 found no direct causal relationship between sleeping with a light on and the development of nearsightedness. The follow-up study showed that children who develop nearsightedness are more likely to have parents who are nearsighted, suggesting (but not proving) a genetic cause. It also showed that parents who are nearsighted are just more likely to leave the light on!

In the above example, the original scientific observation was stated correctly (lights on correlate with nearsightedness). But anyone who became convinced that sleeping with a light on causes nearsightedness would have been wrong. Be skeptical of causal statements that are based only on a good correlation, for the true cause may not be obvious at first. (See MJ’s Human Biology Blog, Correlation Versus Causation.)

Of course, a close correlation is likely whenever a true causal relationship does exist. So although a correlation does not necessarily prove causation, it can be a strong hint that you may have found the true cause, or at least that the true cause is nearby and may even be linked to both of the variables you’re observing.

**Recap** Healthy skepticism, a basic understanding of statistics, and an ability to read graphs are important tools for critical thinking. Know anecdotal evidence when you see it, and appreciate the differences between fact and conclusion and between correlation and causation.

### 1.6 The role of science in society

How do we place science in its proper perspective in our society? Why do we bother spending billions of dollars on scientific research when there are people starving in the streets? These are vital questions for all of us, so let’s look at why we study the natural world in the first place.

**Science improves technology and the human physical condition**

Science gives us information about the natural world upon which we can base our societal decisions. Throughout history some of the greatest benefits of science have been derived from the application of science, called technology, for the betterment of humankind (Figure 1.12). Time and time again, scientific knowledge has led to technological advances that have improved our lives. For example, the development of vaccines has saved millions of lives, and the use of GPS technology has revolutionized navigation.

**Figure 1.12 Benefits of science**. These photos show typical scenes of scientists and the application of science (technology) for the betterment of the human condition.