Almost all journals devote one page or more to "Instructions to Authors," in which specific information is conveyed regarding length of the manuscript, general format, figures, conventions, references, and so on. Skim this section to get an idea of what journal editors expect from scientists who wish to have their work published.

Because most beginning biology students find journal articles hard to read, a sample student laboratory report is given in Chapter 6. Read the comments in the margins as you peruse the report to familiarize yourself with the basics of scientific paper format and content, as well as purpose, audience, and tone.

Chapter 4

# Step-by-Step Instructions for Preparing a Laboratory Report or Scientific Paper

In order to prepare a well-written laboratory report according to accepted conventions, the following skills are required:

- A solid command of the English language
- An understanding of the scientific method
- An understanding of scientific concepts and terminology
- Advanced word processing skills
- Knowledge of computer graphing software
- The ability to read and evaluate journal articles
- The ability to search the primary literature efficiently
- The ability to evaluate the reliability of Internet sources

If you are a first- or second-year college student, it is unlikely that you possess all of these skills when you are asked to write your first laboratory report. Don't worry. The instructions in this chapter will guide you through the steps involved in preparing the first draft of a laboratory report. Revision is addressed in the next chapter, and the Appendices will help you with word processing and graphing tasks.

## Timetable

Preparing a laboratory report or scientific paper is hard work. It will take much more time than you expect. Writing the first draft is only the first step. You must also allow time for editing and proofreading (revision). If you work on your paper in stages, the final product will be much better than if you try to do everything at the last minute.

**TABLE 4.1** Timetable for writing your laboratory report

| Time Frame | Activity | Rationale |
|---|---|---|
| Day 1 | Complete laboratory exercise. | It's fun. Besides, you need data to write about. |
| Days 2–3 | Write first draft of laboratory report. | The lab is still fresh in your mind. You also need time to complete the subsequent tasks before the due date. |
| Day 4 | Proofread and revise first draft (hard copy). | Always take a break after writing the first draft and before revising it. This "distance" gives you objectivity to read your paper critically. |
| Day 5 | Give first draft to a classmate for review. | Your peer reviewer is a sounding board for your writing. He/she will give you feedback on whether what you intended to write actually comes across to the reader. You may wish to alert your peer reviewer to concerns you have about your paper (see "Get Feedback" in Chapter 5). |
| | Arrange to meet with your classmate after he/she has had time to review your paper ("writing conference"). | An informal discussion is useful for providing immediate exchange of ideas and concerns. |
| Day 6 | Peer reviewer reviews laboratory report. | The peer reviewer should review the paper according to two sets of criteria. One is the conventions of scientific writing as described in "Scientific Paper Format" in Chapter 3, and the other is the set of questions in "Get Feedback" in Chapter 5. |
| | Hold writing conference during which the reviewer returns the first draft to the writer. | An informal discussion between the writer and the reviewer is useful to give the writer an opportunity to explain what he/she intended to accomplish, and for the reviewer to provide feedback. |
| Days 6–7 | Revise laboratory report. | Based on your discussion with your reviewer, revise as necessary. Remember that you do not have to accept all of the reviewer's suggestions. |
| Day 8 | Hand in both first draft and revised draft to instructor. | Your instructor wants to know what you've learned (we never stop learning either!). |

The timetable outlined in Table 4.1 breaks the writing process down into stages, based on a one-week time frame. You can adjust the time frame according to your own deadlines.

## Format your report correctly

Although content is important, the appearance of your paper is what makes the first impression on the reader. If the pages are out of order and the ink is faded, subconsciously or not, the reader/evaluator is going to associate a sloppy paper with sloppy science. You cannot afford that kind of reputation. In order for your work to be taken seriously, your paper has to have a professional appearance.

Scientific journals specify the format in their "Instructions to Authors" section. If your instructor has not given you specific instructions, the layout specified in Table 4.2 will give your paper a professional look.

Consult the sample "good" student laboratory report in Chapter 6 for an overview of the style and layout. An electronic file called "Biology Lab Report Template," available at <http://sites.sinauer.com/Knisely4e> is formatted according to the guidelines of Table 4.2 and provides prompts that help you get started writing in scientific paper format. For details on how to format documents in Microsoft Word, see the "Commands in Word 2010" section in Appendix 1.

## Computer savvy

Know your PC and your word processing software. Most of the tasks you will encounter in writing your laboratory report are described in Appendix 1, "Word Processing in Microsoft Word 2010" and Appendix 2, "Making Graphs in Microsoft Excel 2010 and Excel for Mac 2011." If there is a task that is not covered in these appendices, write it down and ask an expert later.

**TABLE 4.2 Instructions to authors of laboratory reports**

| Feature | Layout |
|---|---|
| Paper | 8½" x 11" (or DIN A4) white bond |
| Margins | 1.25" left and right; 1" top and bottom |
| Font size | 12 pt (points to the inch) |
| Typeface | Times Roman or another *serif* font. A serif is a small stroke that embellishes the character at the top and bottom. The serifs create a strong horizontal emphasis, which helps the eye scan lines of text more easily. |
| Symbols | Use word processing software. Do not write symbols in by hand. |
| Pagination | Arabic number, top right on each page except the first |
| Justification | Align left/ragged right or Full/even edges |
| Spacing | Double |
| New paragraph | Indent 0.5" |
| Title page (optional) | Title, authors (your name first, lab partner second), class, and date |
| Headings | Align headings for Abstract, Introduction, Materials and Methods, Results, Discussion, and References on left margin or center them. Use consistent format for capitalization. Do not start each section on a new page unless it works out that way coincidentally. Keep section heading and body together on the same page. |
| Subheadings | Use sparingly and maintain consistent format. |
| Tables and figures | Incorporate into text as close as possible after the paragraph where they are first mentioned. Use descriptive titles, sequential numbering, proper position above or below visual. May be attached on separate pages at end of document, but must still have proper caption. Keep table/figure and its caption together on the same page. |
| Sketches | Hand-drawn in pencil or ink. Other specifications as in "Tables and figures" above. |
| References | Citation-Sequence System: Make a numbered list in order of citation. |
| | Name-Year System: List references in alphabetical order by the first author's last name. Use a hanging indent (all lines but the first indented) to separate individual references. |
| | Both systems: Use accepted punctuation and format. |
| Assembly | Place pages in order, staple top left. |

If you run into a major problem that prevents you from using your PC, you should have a backup plan in place (familiarity with another PC).

Always back up your files somewhere other than your computer's hard drive. Options may include a USB flash drive (also called a jump drive or thumb drive), an external hard drive, or online. Online options include cloud services such as Google Drive, saving your files to your organization's server, or emailing files to yourself. See the section "Backing up your files" on pp. 198–200 for more information.

Save your file frequently while writing your paper by clicking 🖫 on the Quick Access Toolbar. You can also adjust the settings for automatically saving your file by clicking **File | Options | Save | Save AutoRecover information every __ minutes**.

Install antivirus software on your computer and always check flash drives for viruses before you use them. Beware of files attached to email messages. Do not open attachments unless you are sure they come from a reliable source.

Store flash drives with their caps on to keep dust out. Protect them from excess humidity, heat, and cold. Only remove a flash drive from a computer after you eject it and the message "Safe to Remove Hardware" is displayed.

If you must eat and drink near a computer, keep beverages and crumbs away from the hard drive and keyboard.

## Getting Started

Set aside 1 hour to begin writing the laboratory report as soon as possible after doing the laboratory exercise. Turn off your cell phone and get off Facebook, Twitter, YouTube, and email. Writing lab reports requires your full concentration. What matters is the quality, not the quantity, of time you spend on your assignments. Promise yourself a reward for time well spent.

### *Reread the laboratory exercise*

You cannot begin to write a paper without a sense of purpose. What were the objectives of your experiment or study? What questions are you supposed to answer? Take notes on the laboratory exercise to prevent problems with plagiarism when you write your laboratory report.

### *Organization*

If your instructor provided a rubric or other instructions for organizing your lab report, follow the instructions exactly. Otherwise use the standard IMRD format, as described in Chapter 3.

### Audience

Scientific papers are written for scientists. Similarly, laboratory reports should be written for an audience of fellow student-biologists, who have a knowledge base similar to your own. When deciding how much background information to include, assume that your audience knows only what you learned in class. Use scientific terminology, but define any terms known only to experts ("jargon").

Write for an audience of fellow scientists, not students in a classroom situation. Note the difference between the original text and the revision in the following examples:

**FAULTY:** The experiments performed by the students dealt with how different wavelengths of light affect seed germination.

**REVISION:** The purpose of the experiment was to determine how different wavelengths of light affect seed germination.

**FAULTY:** The purpose of this experiment is to become acquainted with new lab techniques such as protein analysis, serial dilutions, and use of the spectrophotometer.

**REVISION:** The purpose of this experiment was to use the biuret assay to determine protein concentration in egg white.

### Writing style

Laboratory reports are formal written assignments. Avoid slang and contractions and choose words that reflect the serious nature of scientific study. Readers of scientific papers trust the scientific method and are confident that the facts speak for themselves. For this reason, write objectively—that is, do not make judgments. When making a statement that may not be obvious to the audience, always back it up by citing an authoritative source or by providing experimental evidence. Because the focus is on the science, not the scientist, passive voice is used more frequently (especially in the Materials and Methods section) than in other kinds of writing. Use active voice in the other sections, however, because it makes sentences shorter and more dynamic.



Past and present tense have specific connotations in scientific papers. Authors use present tense to make *general statements* that the scientific community agrees are valid. Statements that are generally valid include explanations of phenomena based on experimental results that have been replicated by many scientists. Therefore, use present tense in the Introduction and Discussion sections when describing information accepted by the scientific community, and cite the source of any information that is not common knowledge for your audience. On the other hand, authors use past tense to limit interpretations and conclusions to *their own work*. For this reason, use past tense in the Materials and Methods and Results sections, and whenever you are describing work that you personally carried out.

## Start with the Materials and Methods Section

The order in which you write the different sections is not the order in which they appear in the finished laboratory report. The rationale for this plan will become obvious as you read on. The Materials and Methods section requires the least amount of thought, because you are primarily restating the procedure in your own words.

### Tense

When you write your laboratory report, describe the procedure in *past*, not present, tense because (1) these are completed actions and (2) you are describing your own work. Do *not* copy the format of your laboratory exercise, in which the instructions may be arranged in a numbered list and the imperative (command) form of verbs may be used for clarity.

### Voice

There are two grammatical voices in writing: active and passive. In active voice, the subject *performs* the action. In passive voice, the subject *receives* the action. Passive voice is preferred in the Materials and Methods section because the subject that receives the action is more important than who performed it. The logic is that anyone with the appropriate training should be able to perform the action. Consider the following examples:

**ACTIVE VOICE:** I peeled and homogenized the potatoes.

**PASSIVE VOICE:** The potatoes were peeled and homogenized.

The sentence written in active voice is more natural and dynamic, but it shifts the emphasis from the subject, "the potatoes" to "I." Passive voice places the emphasis on the potatoes, where it belongs. Because sentences written in passive voice tend to be longer and less direct than those written in active voice, try to use active voice when the performer (you) is not the subject of the sentence.

### *Level of detail*

A well-written Materials and Methods section will *provide enough detail to allow someone with appropriate training to repeat the procedure.* For example, for a **molecular biology** procedure, include essential details such as the concentration and pH of solutions, reaction and incubation times, volume, temperature, wavelength (set on a spectrophotometer), centrifugation speed, dependent and independent variables, and control and treatment groups. On the other hand, *do not describe routine lab procedures* such as:

- How to calculate molarity or use $C_1V_1 = C_2V_2$ to make solutions
- Taring a balance before use
- Using a vortex mixer to ensure that solutions are well mixed
- Describing how to zero (blank) a spectrophotometer before measuring the absorbance of the samples
- Explaining what type of serological pipette or micropipettor is appropriate for a particular volume
- Designating the type of flasks or beakers to use
- Specifying the duration of the entire study ("In our two-week experiment, ...")

For a **field experiment**, however, time *is* important. When observing or collecting plants and animals in nature, be sure to include in the Materials and Methods section time of day, month, and year; sampling frequency; location and dimensions of the study site; sample size; and statistical analyses. Depending on the focus of your lab report, it may also be prudent to describe the geology, vegetation, climate, natural history, and other characteristics of the study site which could influence the results.

Here are some guidelines for the level of detail to include in the Materials and Methods section.

**Not enough information.** Include all relevant information needed to repeat the experiment.

FAULTY: In this lab, we mixed varying amounts of BSA stock solution with varying amounts of TBS using a vortex mixer. We used a spectrophotometer to measure absorbance of the 4 BSA samples, and then we determined the concentration of 4 dilutions of egg white from the standard curve.

EXPLANATION: This procedure does not give the reader enough information to repeat the experiment, because essential details like *what concentrations of BSA* were used to construct the standard curve, *what dilutions of egg white* were tested, and the *wavelength* set on the spectrophotometer have been left out.

REVISION: Bovine serum albumin (BSA) solutions (2, 3, 5, 10 mg/mL) were prepared in tris-buffered saline (TBS). The egg white sample was serially diluted 1/5, 1/15, 1/60, and 1/300 with TBS. The absorbance of all samples was measured at 550 nm using a Spec 20 spectrophotometer.

The following are examples of **too much information**.

**Do not list materials and methods separately.** The wording of the section heading makes it tempting to separate the content into two parts. In fact **materials should not be listed separately** unless the strain of bacteria, vector (plasmid), growth media, or chemicals were obtained from a special or noncommercial source. It will be obvious to the reader what materials are required on reading the methods.

**Describe the solutions, not the containers.**

FAULTY: Eight clean beakers were labeled with the following concentrations of hydrogen peroxide and those solutions were created and placed in the appropriate beaker: 0, 0.1, 0.2, 0.5, 0.8, 1.0, 5.0, and 10.0.

EXPLANATION: Using clean, suitable containers to store solutions is common practice in the laboratory. Putting labels on labware is also a routine procedure. An essential detail missing from this sentence is the units.

REVISION: The following hydrogen peroxide solutions were prepared: 0, 0.1, 0.2, 0.4, 0.8, 1.0, 5.0, and 10.0%.

**Specify the concentrations, not the procedure for making solutions.**

**FAULTY:** To make the dilution, a micropipette was used to release 45, 90, 135, and 180 µL of bovine serum albumin (BSA) into four different test tubes. To complete the dilution, 255, 210, 165, and 120 µL of TBS was added, respectively.

**EXPLANATION:** With appropriate instruction, making dilutions of stock solutions becomes a routine procedure. In the above example, you should assume that your readers can make the solution using the appropriate measuring instruments as *long as you specify the final concentration.*

**REVISION:** The following concentrations of BSA were prepared for the Bradford assay: 300, 600, 900, and 1200 µL/mL.

**Include only essential procedures and write concisely.**

**FAULTY:** The test tubes were carried over to the spectrophotometer and the wavelength was set to 595 nm (nanometer). The spectrophotometer was zeroed using the blank. Each of the remaining 8 samples in the test tubes were individually placed into the empty spec tube, which was then placed in the spectrophotometer where the absorbance was determined.

**EXPLANATION:** The only detail important enough to mention is the wavelength.

**REVISION:** The absorbance of each sample was measured with a Spectronic 20 spectrophotometer at 595 nm.

**Avoid giving "previews" of your data analysis.**

**FAULTY:** A graph was plotted with Absorbance on the *y*-axis and Protein concentration on the *x*-axis. An equation was found to fit the line, then the unknown protein absorbances that fell on the graph were plugged into the equation, and a concentration was found.



**EXPLANATION:** Making graphs is something that you do when you analyze your raw data, but it is not part of the experimental procedure. How and why you chose to organize the data will become obvious to the reader in the Results section, where you display graphs, tables, and other visuals and describe the noteworthy findings.

**REVISION:** Delete this entire passage.

**Cite published sources.** If you are paraphrasing a published laboratory exercise, it is necessary to cite the source (see "Documenting Sources" on pp. 81–94). Unpublished laboratory exercises are not usually cited; ask your instructor to be sure.

## Do the Results Section Next

The Results section is a *summary* of the key findings of your experiment. This section has two components:

- Visuals, such as tables and figures
- A body, or text, in which you describe the results shown in the visuals

When you work on the Results section, you will complete the following tasks, which are often done concurrently, not necessarily sequentially:

- **Analyze the raw data.** Raw data are all the observations and measurements that you recorded in your lab notebook. It is your job as the author to analyze all these data and process the information for the reader. **Do not simply transfer raw data into your lab report** (your instructor may ask you to attach pages from your lab notebook as an appendix, however). Instead, summarize the data by eliminating aberrant results (because you realized that you made a mistake in obtaining these results), averaging replicates, using statistical methods to see possible trends, and/or selecting representative pictures (micrographs or gel images). The goal of data analysis in general is to try to figure out what the data show. More specifically, you compare the results to the predictions that were based on the hypotheses you proposed when designing your experiment. When the results match the predictions, then the hypotheses are supported. Conversely, when the results are unexpected, further research may be required.

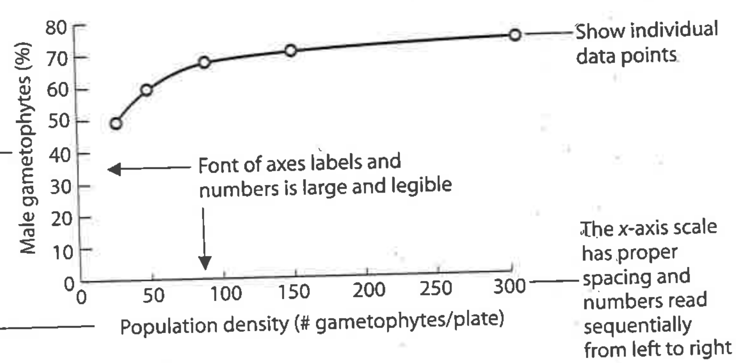
- **Organize summarized data in tables or figures.** When you organize summarized data in a table or plot numerical values on a graph, you may be able to see trends that were not apparent before. Effective visuals are more powerful than words alone and they provide strong support for your arguments. See the "Organizing Your Data" section.

Text describing the figure immediately precedes the figure. Skip a line before and after the figure.

The percentage of male gametophytes increased with population density initially, but above 75 gametophytes/plate, the percentage of males leveled out at about 72% (Figure 1).

Refer to the figure number in parentheses

Dependent variable on y-axis




Independent variable on x-axis

1 space 2 spaces (no colon or period)

Figure caption is positioned below the figure. It consists of Arabic number and title.

Figure 1 Effect of population density on the percentage of male gametophytes in wild type *Ceratopteris*

Descriptive title that stands alone. Title is not simply y-axis label versus x-axis label.

**Figure 4.1** Excerpt from a Results section showing a properly formatted figure with one line (data set); text that describes the figure precedes it.



- **Decide in which order to present the tables and figures.** The sequence should be logical, so that the first visual provides a basis for the next or so that the reader can easily follow your line of reasoning.
- **Describe each visual in turn and refer to it in parentheses.** Describe the most important thing you want the reader to notice about the visual. Refer to the visual by number in parentheses at the end of the first sentence in which you describe it. Position the visual after the descriptive paragraph (Figure 4.1). Other examples of good descriptions of visuals are given in Figures 4.2 and 4.4.

### *Writing the body of the Results section*

The body of the Results section is a description of the important findings of your study or experiment.

**Tense.** Use *past* tense, since you are referring specifically to your own results. Do not use present tense, because present tense would indicate that the scientific community has already agreed that your results are generally valid.

**Voice.** Use active voice as much as possible to make your descriptions clear and concise.

**Style.** Refer to Figure 4.1 as you read the following examples, which illustrate some of the common problems you may encounter when writing your Results section.

Report the results objectively, **without explaining or interpreting** them.

FAULTY: As population density increased, the percentage of male gametophytes also increased due to the effect of the pheromone antheridiogen.

EXPLANATION: Do not try to explain the results in the Results section. Save interpretation for the discussion.

REVISION: The percentage of male gametophytes increased with population density initially, but above 75 gametophytes/plate, the percentage of males leveled out at about 72% (Figure 1).

**Make every sentence meaningful.**

**FAULTY:** The results of the testing showed that population density affected the percentage of male gametophytes.

**EXPLANATION:** *How* did population density affect the percentage of males?

**FAULTY:** The final analyzed data from the lab showed that there was a population density at which the number of gametophytes was no longer increasing.

**EXPLANATION:** *What was the density* at which the percentage of males no longer increased?

**FAULTY:** Figure 1 represents the effect of population density on the percentage of male gametophytes. The class data was averaged for the effect that each density had on the number of males.

**EXPLANATION:** *What was the effect* of population density on the percentage of males?

**REVISION:** The percentage of male gametophytes increased with population density initially, but above 75 gametophytes/plate, the percentage of males leveled out at about 72% (Figure 1).

Similarly, **eliminate unnecessary introductory phrases** such as:

- It was found that...
- The results show that...
- There is a general trend where...
- It can be determined that...
- When the test plates were observed and counted, ...
- When the values for each calculation had been obtained, it was clear that...

**REVISION:** Delete the introductory phrase and begin the sentence with an actual result.



Always **refer to the visual** that contains the data that you are describing

**FAULTY:** The results that were obtained while completing the lab clearly showed that the percentage of male gametophytes increased with population density initially, but above 75 gametophytes/plate, the percentage of males leveled out at about 72%.

**FAULTY:** The figure below shows that there was a linear relationship between population density and percentage of male gametophytes up to about 75 gametophytes/plate. At higher densities, the percentage of males stayed the same.

**EXPLANATION:** *Which figure* contains the results the author is describing?

**REVISION:** The percentage of male gametophytes increased with population density initially, but above 75 gametophytes/plate, the percentage of males leveled out at about 72% (Figure 1).

## Equations

Equations are technically part of the text and should *not* be referred to as figures. Equations are set off from the rest of the text on a separate line. If you have several equations and need to refer to them unambiguously in the body of the Results (or another) section, number each equation sequentially and place the number in parentheses on the right margin. For example:

$$\text{Absorbance} = -\log T \qquad (1)$$

In Microsoft Word, to center an equation and right-align the equation number, insert a center tab stop and a right tab stop as shown.

If you are presenting a sequence of calculations, align the = symbol in each line, as in the following example:

Protein concentration of the unknown sample was determined using the equation of the biuret standard curve. The measured

**TABLE 4.3 Types of graphs and their purpose**

| Graph | Purpose | Example |
|---|---|---|
| Histogram | To show the distribution of a quantitative variable. | Distribution of grades on an exam. *Y*-axis shows number of students; *x*-axis shows numerical score on the exam. |
| Scatterplot | To show the relationship between two quantitative variables measured on the same individuals. Look for an overall pattern and for deviations from that pattern. If the points lie close to a straight line, a linear trendline may be superimposed on the scatter graph. The correlation, *r*, indicates the strength of the linear relationship. | Relationship between shell length and mass. If we are just looking for a pattern, it doesn't matter which variable is plotted on which axis. If we suspect that mass depends on length, plot mass on the *y*-axis and length on the *x*-axis. Look at the form, direction, and strength of the relationship. |
| Line graph | To show the relationship between two quantitative variables. One variable may be dependent on the other. The variable that is being manipulated is called the independent or explanatory variable. The variable that changes in response to the independent variable is called the dependent or response variable. By convention, the independent variable is plotted on the *x*-axis and the dependent variable is plotted on the *y*-axis. Error bars may be included to show variability. | Relationship between enzyme activity and temperature. Because temperature is the variable that is being manipulated, it is plotted on the *x*-axis. Because enzyme activity is the response being measured, it is plotted on the *y*-axis. |

absorbance value was substituted for $y$, and the equation was solved for $x$ (the protein concentration):

$$y = 0.0417x$$
$$0.225 = 0.0417x$$
$$5.40 = x$$

Thus, the protein concentration of the sample was 5.40 mg/mL.



**TABLE 4.3 *Continued***

| Graph | Purpose | Example |
|---|---|---|
| Scatterplot with regression line | To predict the value of *y* for a given value of *x* or vice versa. The response variable must be dependent on the explanatory variable and the relationship must be linear. The regression line takes the form $y = mx + b$, where m is the slope and b is the y-intercept. | Standard curve for a protein assay. Protein concentrations of a standard such as BSA are plotted on the *x*-axis. Absorbance (measured by a spectrophotometer) for each concentration is plotted on the *y*-axis. A regression line is fitted to the data. To predict the protein concentration of a sample (*x*), measure its absorbance (*y*) and solve the regression equation for *x*. |
| Bar graph | To show the distribution of a categorical (non-quantitative) variable. | Effect of different treatments on plant height. One axis shows the treatment category and the other shows the numerical response. |
| Pie graph | To show the distribution of a categorical (non-quantitative) variable in relation to the whole. All categories must be accounted for so that the pie wedges total 100%. | Composition of insects in a backyard survey. Each wedge represents the percentage of an order of insects. Orders with low representation may be combined into an "Other" wedge to complete the pie. |

In Microsoft Word 2008 or later, type equations using the Equation Tool, accessed by clicking **Insert | Symbols | Equation**. Type the first equation into the box. Press **Enter**. Repeat the process for each equation in the group. To align the group of equations on the equal sign, select all of the equations, right-click, and select **Align at =**. This method does not work if each line has a right-aligned equation number. In that case, the equations have to be aligned manually.

## *Preparing visuals*

The most common visuals in scientific writing are tables and figures. A **table** is defined by Webster's dictionary as "a systematic arrangement of data usually in rows and columns for ready reference." A **figure** is any visual that is not a table. Thus, line graphs, bar graphs, pie graphs (also called pie charts), drawings, gel photos, X-ray images, and microscope images are all called *figures* in scientific papers.

The type of visual you use depends on the objectives of your study or experiment and the nature of the data. Use a **table** when

- The exact numbers are more important than the trend.
- Statistics such as sample size, standard error, and P-values are used to support your conclusions.
- Arranging categorical variables and other non-quantitative information makes it easier to interpret the results.

Use a **graph** to show relationships between or among variables. The type of graph that can be used is often dictated by the nature of the variables—quantitative or categorical. **Categorical variables** are groups or categories that have no units of measurement (treatment groups, age groups, habitat, etc.). Bar graphs and pie graphs are commonly used to display results involving categorical variables. **Quantitative variables**, on the other hand, have numerical values with units. Line graphs (also called XY graphs) and scatter graphs (also called scatterplots) display relationships between quantitative variables. Some of the graphs frequently encountered in the field of biology are summarized in Table 4.3 and described individually in the following sections.

Do not feel that you have to have visuals in your lab report. If you can state the results in a sentence, then no visual is needed (see Example 1 in the "Organizing Your Data" section).

## Tables

Tables are used to display large quantities of numbers and other information that would be tedious to read in prose. Arrange the categories vertically, rather than horizontally, as this arrangement is easier for the reader to follow (see, for example, Table 1 in Figure 4.2). List the items in a logical order (e.g., sequential, alphabetical, or increasing or decreasing value). Include the units in each column heading to save yourself the trouble of writing the units after each number entry in the table.

By convention, tables in scientific papers do not have vertical lines to separate the columns, and horizontal lines are used only to separate the table caption from the column headings, the headings from the data, and the data from any footnotes. The tables in this book are formatted in this style.

Give each table a caption that includes a number and a title. Center the caption or align it on the left margin *above* the table. Use Arabic numbers, and number the tables consecutively in the order they are discussed in the text. Notice that in this book, the table and figure numbers are preceded by the chapter number. This system helps orient the reader in long manuscripts, but is not necessary in short papers like your laboratory report.



Text describing the table immediately precedes the table. Skip a line before and after the table.

Abscisic acid (ABA) and gibberellic acid (GA) had opposite effects on seed germination (Table 1). The majority of the seeds (92.5%) germinated in the light, but fewer germinated when they were exposed to 0.05–8 μM ABA. On the other hand, only 25% of the seeds germinated in the dark. This percentage increased when the seeds were exposed to 10–40 μM GA.

Refer to the table number in parentheses

Arabic number

1 space

2 spaces (no colon or period)

Table caption is positioned above table. It consists of Arabic number and title.

Table 1  Interaction between light and hormones in the germination of light-sensitive lettuce seeds

Descriptive title. Essence of table can be understood without referring to the body of the Results section.

First word of column heading is generally capitalized (except for words such as pH and cDNA that begin with a lower case letter)

| Light treatment | ABA (μM) | GA (μM) | Seed germination (%) |
|---|---|---|---|
| White fluorescent light | 0 | | 92.5 |
| | 0.05 | | 15 |
| | 2 | | 8 |
| | 8 | | 0 |
| Dark | | 0 | 25 |
| | | 10 | 42 |
| | | 20 | 63 |
| | | 40 | 37 |

Column headings include units in parentheses where appropriate

Categories (dependent variables) are arranged in columns, not rows

Horizontal lines are used sparingly

No vertical lines are used

**Figure 4.2** Excerpt from a Results section showing a properly formatted table preceded by the text that describes the data in the table.

From the table title alone, the reader should be able to understand the essence of the table without having to refer to the body (text) of the Results section. For simple tables, it may suffice to use a precise noun phrase rather than a full sentence for the title. For more complex tables, one or more full sentences may be required. Either way, English grammar rules apply:

- Do not capitalize common nouns (*general* classes of people, places, or things) unless they begin the phrase or sentence.
- Capitalize proper nouns (names of *specific* people, places, or things).
- Do not capitalize words that start with a lower case letter (for example, pH, mRNA, or cDNA), even if they begin a sentence.

Some examples of faulty and preferred titles are shown below.

**FAULTY:** Table 1 The Relationship Between Light and Hormones in the Germination of Light-Sensitive Lettuce Seeds

**EXPLANATION:** Do not capitalize common nouns.

**FAULTY:** Table 1 Table of interaction between light and hormones in the germination of light-sensitive lettuce seeds

**EXPLANATION:** Do not start a title with a description of the visual.

**FAULTY:** Table 1 Seed germination data

**EXPLANATION:** Do not write vague and undescriptive titles.

**REVISION:** Table 1 Interaction between light and hormones in the germination of light-sensitive lettuce seeds

A table is always positioned *after* the text in which you refer to it (see Figure 4.2). Refer to the table number in parentheses at the end of the first sentence in which you describe the table contents. That way the reader can refer to the table as you describe what you consider to be important.

In your laboratory report, it is not necessary to include a table when you already have a graph that shows the same data. Make *either* a table *or* a graph—not both—to present a given data set.

Tables can be constructed in either Microsoft Word (see "The Insert Tab" section in Appendix 1) or Microsoft Excel (see Figure A2.6 in Appendix 2).

**Table preparation checklist**

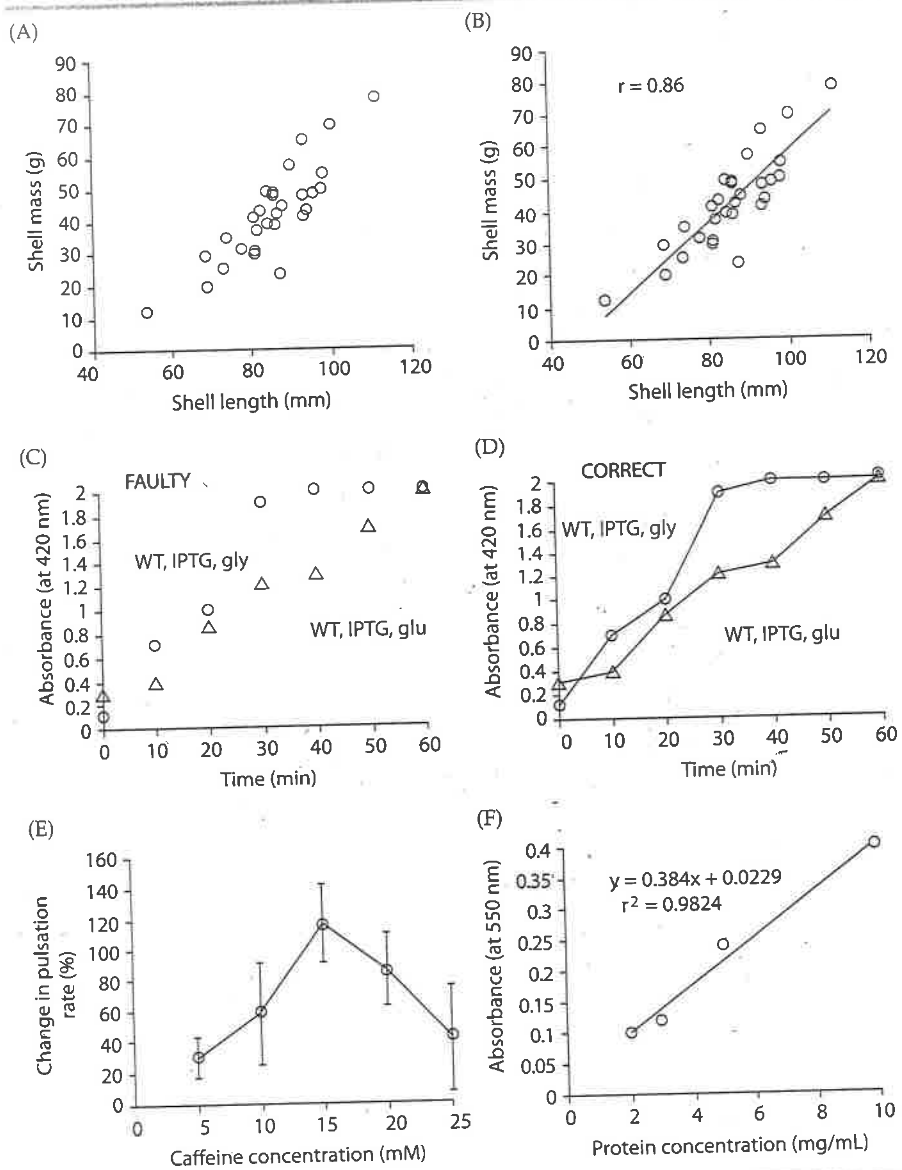
- ☐ Categories arranged in columns, not rows
- ☐ Column headings include units (where appropriate)
- ☐ Format correct (minimal lines)
- ☐ Table title descriptive
- ☐ Table title grammatically correct
- ☐ Table caption positioned above the table

### *Line graphs (XY graphs) and scatterplots*

**Line graphs** display a relationship between **two or more quantitative variables**. What we hope to learn from the data in part determines the format of the XY graph (Figure 4.3). For example, in **observational studies**, scientists observe individuals and measure variables that they are interested in. Quite often, the purpose of an observational study is to look for a pattern in nature. Patterns may be easier to spot when the numerical data are plotted as a **scatterplot**, one kind of line graph in which the individual data points are not connected (Figure 4.3A). By convention, if one of the variables explains or influences the other, then this so-called explanatory or **independent variable** is plotted on the $x$-axis. The variable that shows the response, also called the **dependent variable**, is plotted on the $y$-axis. In some observational studies, there may not be a causative relationship between the two variables, in which case it doesn't matter which variable is plotted on which axis.

The first step in describing a pattern on a scatterplot is to look at the form and direction of the data. The **form** may be linear, curved, clustered, or random; because many relationships in nature are linear, exponential, or logarithmic, keep an eye out for these kinds of forms. The **direction** indicates whether the relationship between the variables is positive (large values for $y$ correspond to large values for $x$ and vice versa) or negative (large values for $y$ correspond to small values for $x$ and vice versa), or if there is no change in $y$ with $x$ or vice versa. Once you've described the form and direction of the scatterplot, try to assess the **strength** of the relationship. How closely do the points follow the form? A lot of scatter and the presence of outliers indicate a weak relationship.

Our eyes are pretty good at recognizing when the data fall on a straight line, but we need a more objective way to assess the strength of the relationship. One such indicator is called correlation ($r$), whose rather complex formula produces values between –1 and 1. Correlation values near 0 indicate a weak linear relationship, with the strength of the relationship increasing as $r$ approaches –1 (when the direction is negative) or 1 (when the direction is positive). When the data in an observational study show a strong linear rela-




tionship, scientists may superimpose a straight line on the scatterplot and display $r$ as a measure of the strength of the relationship (Figure 4.3B).

In observational studies, scientists measure a variable of interest without trying to influence the response. On the other hand, in **experiments**, scientists impose a treatment on individuals and then observe how the treatment



**Figure 4.3** Different line graph formats showing relationships between variables. (A) A scatterplot displays numerical observations with the purpose of determining whether there is a relationship between shell mass and shell length. (B) A scatterplot with a straight line added shows that there is a strong linear relationship between the two variables. (C) The relationship between the independent and dependent variables in each treatment group is hard to see when the points are not connected. (D) The relationship is much easier to see when the points are connected with straight or smoothed lines. (E) Error bars show variability about the mean. (F) A least-squares regression line and its equation are used to predict one variable when the other is known. Regression lines are used only in specific situations when the linear relationship between the two variables is clearly established.

affects their responses. The purpose of an experiment, therefore, is to determine the effect of one variable (the explanatory or independent variable) on another (the response or dependent variable). By convention, the independent variable (the one the scientist manipulates) is plotted on the $x$-axis and the dependent variable (the one that changes in response to the independent variable) is plotted on the $y$-axis.

On a scatterplot, the individual data points are not connected, because the purpose of the graph is to determine the form, direction, and strength of the relationship between the variables. In contrast, in an experiment, scientists want to know **how the imposed treatments affect the response**. To make it easier to see this effect, **the data points are connected by straight or smoothed lines**. Lines avoid confusion particularly when there is more than one data set on a graph (compare Figures 4.3C and D). Never show the lines without the experimental data, however.

Data points displayed on graphs are typically a summary of the raw data, with each point representing the mean value calculated by averaging many replicates. **To show variability in the measured values** (especially when the data are distributed normally about the mean), authors may include **error bars** on their graphs (Figure 4.3E). An explanation of what the error bars represent—standard deviations or standard errors of the mean—should be given in the figure title along with the number of observations.

Finally, **standard curves** represent a special case of line graph, whose purpose is to predict one variable when the other is known. First the data points are plotted as a scatterplot, and then a least-squares regression line (best-fit line) is fitted to the points (Figure 4.3F). The square of the correlation, $r^2$, describes how well the regression line fits the data. The closer the $r^2$ value is to 1, the better the fit. The better the fit, the closer the predicted value will be to the true value of the unknown variable.

Figures are always numbered and titled *beneath* the visual (Figure 4.4; see also Figure 4.1). The captions may be centered or placed flush on the left margin of the report. Arabic numbers are used, and the figures are numbered consecutively in the order they are discussed in the text.

The percentage of male gametophytes increased with population density of the wild type strain, but there were no male gametophytes at any density in the Her 1 strain (Figure 2).

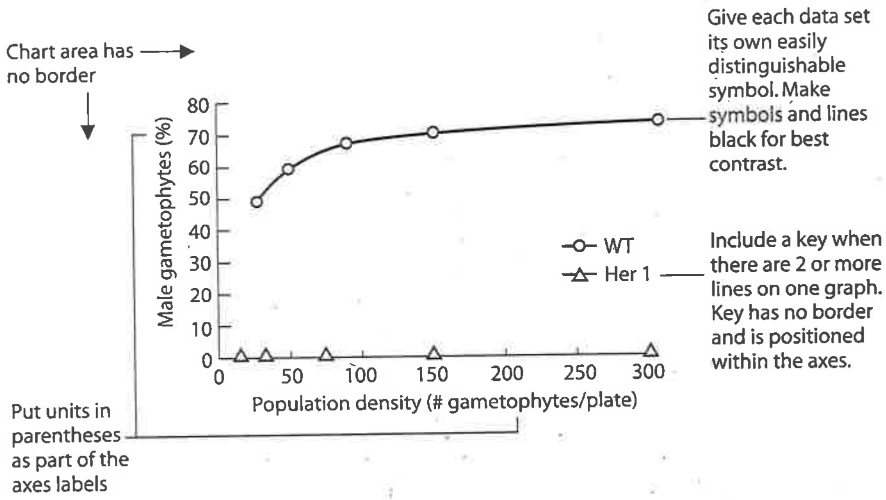



Figure title stands alone

Figure 2 Effect of population density on the percentage of male gametophytes in wild type and Her 1 *Ceratopteris*

Italicize Latin names of genera

**Figure 4.4** Excerpt from a Results section showing a properly formatted figure with two sets of data. A legend (key) is needed to distinguish the two lines. The text that describes the figure precedes it.

From the figure title alone, the reader should be able to understand the essence of the figure without having to refer to the body (text) of the Results section. For simple figures, it may suffice to use a precise noun phrase rather than a full sentence for the title. For more complex figures, one or more full sentences may be required. Either way, English grammar rules apply: Do not capitalize common nouns (*general* classes of people, places, or things) unless they begin the phrase or sentence. Capitalize proper nouns (names of *specific* people, places, or things). Do not capitalize words that start with a lower case letter (for example, pH, mRNA, or cDNA), even if they begin a sentence. Some examples of faulty and preferred titles are shown here.



**FAULTY:** Figure 1 The Effect of Population Density on the Development of Male Gametophytes

**EXPLANATION:** Do not capitalize common nouns.

**FAULTY:** Figure 1 Percentage of male gametophytes vs. population density

**EXPLANATION:** Do not restate the *y*-axis label versus the *x*-axis label as the figure title.

**FAULTY:** Figure 1 shows the effect of population density on the percentage of male gametophytes in wild type *Ceratopteris*

**EXPLANATION:** Separate the figure number and the title.

**FAULTY:** Figure 1 Line graph of the effect of population density on the percentage of male gametophytes in wild type *Ceratopteris*

**EXPLANATION:** Do not start a title with a description of the visual.

**FAULTY:** Figure 1 Averaged class data for C-fern experiment

**EXPLANATION:** Do not write vague and undescriptive titles.

**REVISION:** Figure 1 Effect of population density on the percentage of male gametophytes in wild type *Ceratopteris*

If there is more than one data set (line) on the figure, you have three options:

- Add a brief label (no border, no arrows) next to each line.
- Use a different symbol for each line and label the symbols in a key (as in Figure 4.4). Place the key without a border within the axes of the graph. This is the easiest option if you are using Excel to plot your data.
- If the first two options make the figure look cluttered, identify the symbols in the figure caption.

All three formats are acceptable in scientific papers as long as you use them consistently.

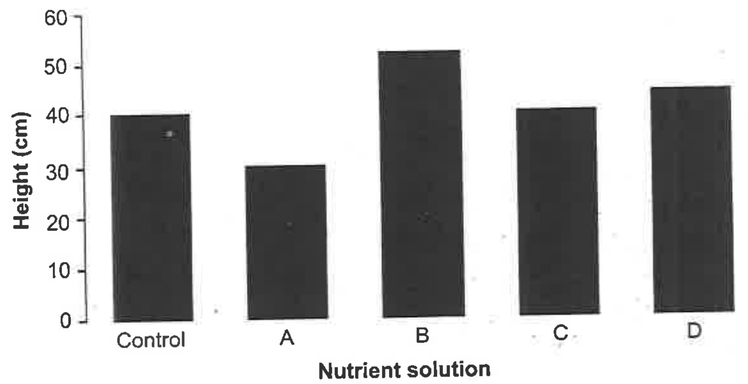



**Figure 4.5** Final height of corn plants after 4-week treatment with different nutrient solutions. This figure is an example of a column graph.

Figures in your laboratory report should be prepared according to the guidelines specified by the Council of Science Editors (CSE Manual 2006). Although you may wish to plot a rough draft of your graphs by hand, you should learn how to use computer plotting software to make graphs. Microsoft Excel is a good plotting program for novices (see Appendix 2) because it is readily available and fairly easy to use. The time you invest now in learning to plot data on the computer will be invaluable in your upper-level courses and later in your career.

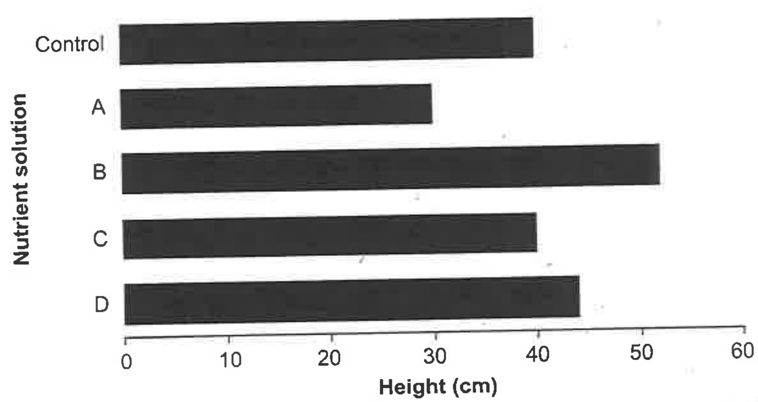



**Figure 4.6** Final height of corn plants after 4-week treatment with different nutrient solutions. This figure is an example of a horizontal bar graph.



## *Bar graphs*

A bar graph allows you to compare individual sets of data when **one of the variables is categorical** (not quantitative)—this is the main difference between line graphs and bar graphs. Bar graphs are more flexible than pie charts because any number of categories can be compared; the percentages do not have to total 100%. Error bars may be centered at the top of each data bar to show variability in the measured data. When the data bars are black, only half error bars are used.

Consider an experiment in which you want to compare the final height of the same species of plant treated with four different nutrient solutions. The nutrient solution is the non-numerical, categorical variable; the height is the response variable. The data bars can be arranged vertically (Figure 4.5) or horizontally (Figure 4.6). The arrangement you use often depends on your sub-discipline, but the horizontal arrangement is more practical when the category labels are long.

The bars should be placed sequentially, but if there is no particular order, then put the control treatment bar far left in column graphs or at the top in horizontal bar graphs. Order the experimental treatment bars from shortest to longest (or vice versa) to facilitate comparison among the different conditions. The baseline does not have to be visible, but all the bars must be aligned as if there were a baseline.

The bars should always be wider than the spaces between them. In a graph with clustered bars, make sure each bar has sufficient contrast so that it can be distinguished from its neighbor (Figure 4.7). Instructions for plotting bar graphs in Excel 2010 are given in Appendix 2.

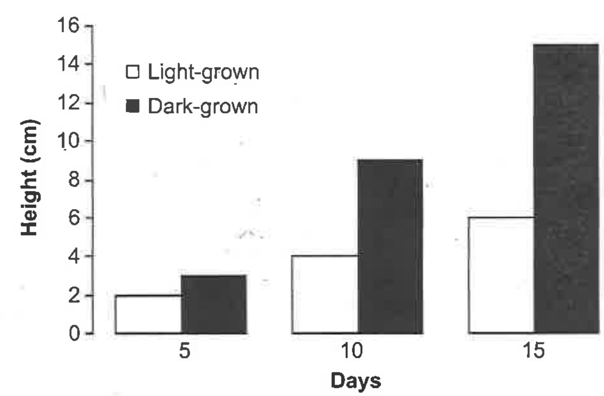



**Figure 4.7** Difference in height of groups of light-grown and dark-grown bean seedlings at 5, 10, and 15 days after planting. This figure is an example of a clustered bar graph. Each bar in the cluster must be easily distinguishable from its neighbor.

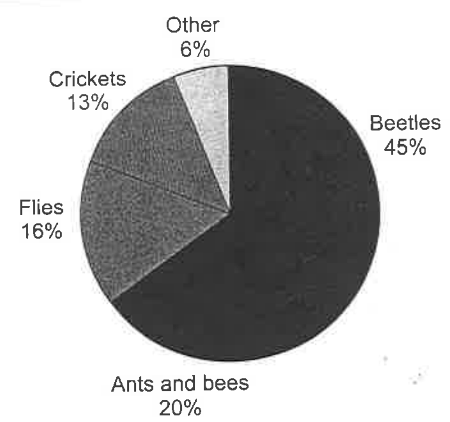



**Figure 4.8** Composition of insects in backyard survey. Pie graphs are used to show data as a percentage of the total data.

## *Pie graphs*

A pie graph is used to show data as a percentage of the total data. For example, if you were doing a survey of insects found in your backyard, a pie graph would be effective in showing the percentage of each kind of insect out of all the insects sampled (Figure 4.8). There should be between 2 and 8 segments in the pie. Place the largest segment in the right-hand quadrant with the segments decreasing in size clockwise. Combine small segments under the heading "Other." Position labels and percentages horizontally outside of the segments for easy reference. Instructions for plotting pie charts in Excel 2010 are given in Appendix 2.

**Figure preparation checklist**

- ☐ Right type of graph
- ☐ Format correct (symbols, lines, legend, axis scale, no gridlines, no border)
- ☐ Figure title descriptive
- ☐ Figure title grammatically correct
- ☐ Figure caption positioned below the figure

## *Organizing your data*

Reread the laboratory exercise to see if your instructor has provided specific guidelines on the kinds of visuals to include in the Results section. If



you have to make the decision on your own, ask yourself the following questions:

- Can I state the results in one sentence? If so, then **no visual** is needed.
- Are the numbers themselves more important than the trend shown by the numbers? If so, then use a **table**.
- Is the trend more important than the numbers themselves? If so, use a **graph**.
  - Are both variables quantitative? If so, then use a **line graph**.
  - Is one of the variables categorical (not quantitative)? If so, then use a **bar graph**.
- Are the results descriptive rather than quantitative? If so, use **photos and images**.

The following examples demonstrate that there may be more than one good way to organize the data. Some visuals may be more appropriate than others, and in some cases, no visual may be the best alternative.

EXAMPLE 1: *Brassica* seeds were placed on filter paper saturated with pH 1, 2, 3, or 4 buffered solutions. The positive control was filter paper saturated with water. After 2 days, 100% of the seeds in the positive control germinated. No seeds germinated in any of the buffered solutions.

POSSIBLE SOLUTION: **No visual** is needed because the results can be summarized in one sentence: "After 2 days, 100% of the seeds that imbibed water germinated, but none of the seeds that were treated with buffered solutions pH 1, 2, 3, or 4 germinated."

EXAMPLE 2: Light-sensitive lettuce seeds placed on filter paper saturated with water were exposed to the same fluence of white fluorescent, red, far-red, green, and blue light treatments as well as darkness, and the percentage that germinated was determined 30 hours later.

POSSIBLE SOLUTION: Since some of the data are categorical rather than quantitative (colors rather than wavelengths of light), either a *table* or a *bar graph* (Figure 4.9) works well to display the results.

(A)

Table 1 Effect of light treatment on percentage of light-sensitive lettuce seeds germinated after 30 hr

| Light treatment | Seed germination (%) |
|---|---|
| Red | 76 |
| White | 65 |
| Blue | 44 |
| Far-red | 38 |
| Green | 37 |
| Dark | 30 |

(B)

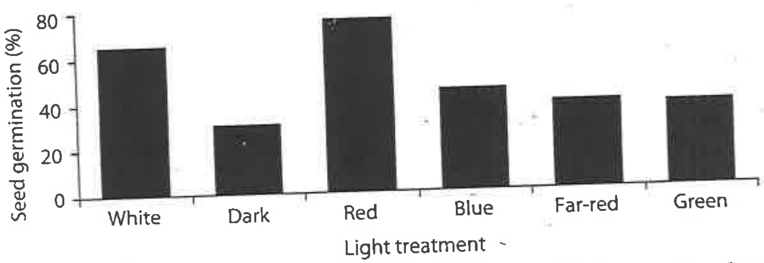



Figure 1 Effect of light treatment on percentage of light-sensitive lettuce seeds germinated after 30 hr

**Figure 4.9** Example 2 data summarized in (A) a table or (B) a bar graph. The positive and negative controls are placed to the left, and, if there is no particular order to the categories (colors in this example), arrange the bars in order of the longest to the shortest (or vice versa).

**INAPPROPRIATE SOLUTION:** A *line graph* is not appropriate because both variables are not quantitative. We only know the colors of light, not the exact wavelengths. *Text only* is **not** appropriate because listing the seed germination percentages in a sentence is tedious to read and hard to comprehend.

**EXAMPLE 3:** The activity of an enzyme (catalase) was monitored at nine different temperatures in order to determine the optimal temperature for maximum activity.



**POSSIBLE SOLUTION:** If your emphasis is on the actual numbers rather than the trend, then display the results in a *table.* If the trend is more important than the numbers, use a *line graph and connect the points* with smoothed or straight lines (Figure 4.10).

(A)

Table 1 Effect of temperature on catalase activity

| Temperature (°C) | Catalase activity (units of product formed · $sec^{-1}$) |
|---|---|
| 4 | 0.039 |
| 15 | 0.073 |
| 23 | 0.077 |
| 30 | 0.096 |
| 37 | 0.082 |
| 50 | 0.040 |
| 60 | 0.007 |
| 70 | 0 |
| 100 | 0 |

(B)

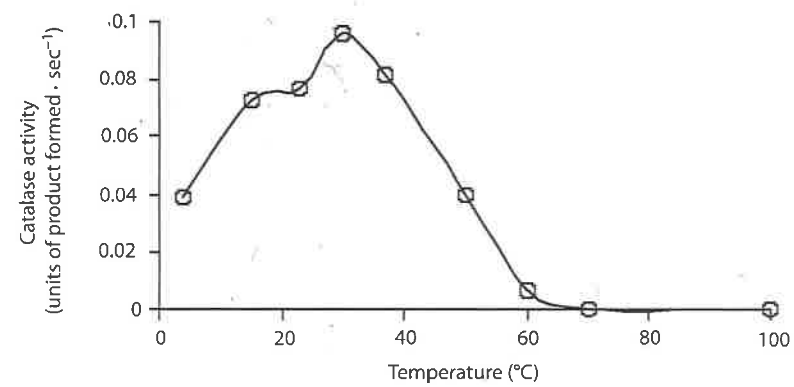



Figure 1 Effect of temperature on catalase activity

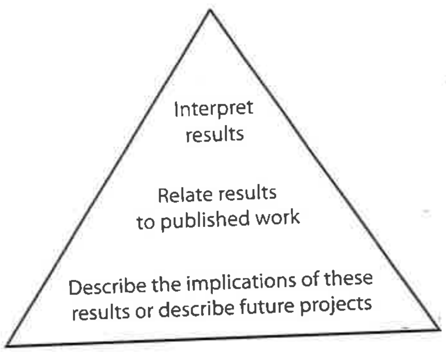
**Figure 4.10** Example 3 data summarized in (A) a table or (B) a line graph. When data are summarized in a table, the emphasis is placed on the numbers rather than on the trend. For the same data, a line graph is more effective than a table in showing the trend.

## Make Connections

Now that the "meat" of your report is done, it's time to describe how your work fits into the existing body of knowledge. These connections are made in the Discussion and Introduction sections.

### *Write the discussion*

The Discussion section gives you the opportunity to **interpret your results, relate them to published findings, and explain why they are important.** The structure of the discussion is specific to broad, as illustrated by the following triangle.




**Tense.** When *describing* your own results, use *past* tense. However, when you use scientific fact to *explain* your results, use *present* tense.

PAST TENSE: The optimal temperature for catalase activity *was* 30°C (Figure 1).

EXPLANATION: Past tense signifies that this statement is limited to your own results.

PRESENT TENSE: Enzyme activity *is* low at cold temperatures because of decreased kinetic energy. At high temperatures, however, enzyme activity *is* low because the enzymes *are* denatured.

EXPLANATION: Present tense signifies that these statements are generally valid and considered to be scientific fact.

**Voice.** Use primarily active voice to make your writing clear and dynamic.



**Style.** When explaining your results, never use the word *prove*. Instead, use words and phrases like *provide evidence for, support, indicate, demonstrate,* or *strongly suggest*. The reason for this choice of words lies in the logic behind the scientific method. If our results match our predictions, then there is evidence that our hypotheses are correct. When many scientists get the same results independently, then the support for a given hypothesis grows. Scientists are reluctant to use the word "prove," because there is always a chance that a future study may provide conflicting evidence.

FAULTY: These results prove that catalase was denatured at temperatures above 60°C.

REVISION: These results strongly suggest that catalase was denatured at temperatures above 60°C.

**Organization.** Start the discussion by **restating the objectives** of the current work. Then **recap each result** and **try to explain it**. Interpret the results so that the reader understands how you arrived at your conclusions. Ideally, there will be a one-to-one correspondence between the important points you address in the Discussion section with the problems or questions you stated in the Introduction section.

Especially in introductory biology labs, the results may not always work out the way we expect. **If your results defy explanation**, consider these possible reasons:

- Human error, including failure to follow the procedure, failure to use the equipment properly, failure to prepare solutions correctly, variability when multiple lab partners measure the same thing, and simple arithmetic errors. If you suspect that human error may have affected your results, then acknowledge its contribution.
- Numerical values were entered incorrectly in the computer plotting program.
- Sample size was too small.
- Variability was too great to draw any conclusions.

If you can rule out these possibilities, discuss your results with your lab partner, teaching assistant, or instructor. If there is an obvious error, an "outsider" may be able to spot it immediately. In any event, having a discussion with a knowledgeable individual may help you understand the concept, even if you obtained unexpected results.

Next, **compare your results with those in the literature**. Do your findings support or contradict results published previously? Did you use a different method, but still obtain the same result? Or could a different method account for a conflicting result? If there are inconsistencies in your data, point them out. Discuss possible sources of error.

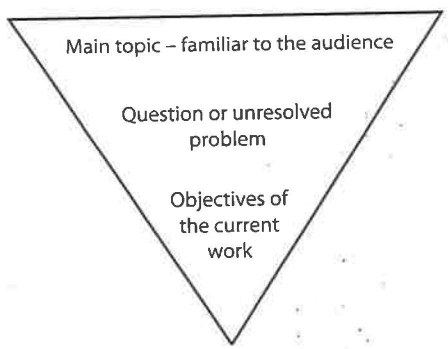
Read the Discussion section of published papers to learn how scientists present convincing arguments for their conclusions. Always paraphrase information you obtained from others and cite the source (see "Documenting Sources" on pp. 81–94).

Finally, if warranted, **add a conclusion about the significance of your work.** You may describe how your results apply to a related field or possible future work that focuses on an interesting observation.

### *Write the introduction*

After having written drafts of the Materials and Methods, Results, and Discussion sections, you should be intimately familiar with the procedure, the results, and what the results mean. Now you are in a position to put your investigation into perspective. What was already known about the topic? Were there any unanswered questions? Why did you carry out this investigation?

The structure of the introduction is broad to specific, just the opposite of that of the discussion.




**Organization.** The introduction consists of two main parts:

- Background information from the literature, and
- Objectives of the current work.

The opening sentence of the Introduction section is usually a **general observation or result** familiar to readers in that discipline. Subsequent sentences **narrow down the topic** to the specific focus of the current study. Subsequent paragraphs then provide background information from the literature and **describe unanswered questions** or inconsistencies. The **objectives of the current work** are usually stated in the last paragraph of the Introduction section.



**Tense.** In the course of providing background information on your topic, you will discuss scientific fact that is based on findings published in research papers. When describing scientific fact, use *present* tense. When stating the objectives of your study, use *past* tense. Past tense is preferred because proposing objectives is a completed action that you carried out before starting your actual study.

**Voice.** Active voice is preferred because it makes sentences shorter and more direct.

## Effective Advertising

The whole point of writing your paper is to communicate your work to your fellow scientists. The abstract and the title are the primary tools potential readers will use to decide whether or not they are interested in your work.

### *Write the abstract*

The abstract is a **summary of the entire paper** in 250 words or less. It contains:

- An introduction (scope and purpose)
- A short description of the methods
- The results
- Your conclusions

There are no literature citations or references to figures in the abstract.

After the title, the abstract is the most important part of the scientific paper used by readers to determine initial interest in the author's work. Abstracts are indexed in databases that catalogue the literature in the biological sciences. If an abstract suggests that the author's work may be relevant to your own work, you will probably want to read the whole article. On the other hand, if an abstract is vague or essential information is missing, you will probably decide that the paper is not worth reading. When you write the abstract for your own laboratory report, put yourself in the position of the reader. If you want the reader to be interested in your work, write an effective abstract.

Writing the abstract is difficult because you have to condense your entire paper into 250 words or less. One strategy for doing this is to list the key points of each section, as though you were taking notes on your own paper. Then write the key points in full sentences. Revise the draft for clarity and conciseness using strategies such as using active voice, combining choppy sentences with connecting words, rewording run-on sentences, and eliminating redundancy. With each revision, look for ways to shorten the text so that the resulting abstract is a concise and accurate summary of your work.

The ability to write abstracts is important to a scientist's career. Should you someday wish to present your research at an academic society meeting, such as the Society for Neuroscience, the American Association for the Advancement of Science, or the National Association of Biology Teachers (to name just a few), you will be asked to submit an abstract of your presentation to the committee in charge of the meeting program. Your chances of being among the select field of presenters at these meetings are much better if you have learned to write a clear and intelligent abstract.

### *Write the title*

The title is a **short, informative description** of the essence of the paper. You may choose a working title when you begin to write your paper, but revise the title after subsequent drafts. Remember that readers use the title to determine initial interest in the paper, so descriptive accuracy is the most essential element of your title. Brevity is nice if it can be achieved. Some journals (especially the British ones) are fond of puns and humor in their titles, but this kind of thing may be better left for later in your career.

Here are some examples of vague and undescriptive titles:

FAULTY: Quantitative Protein Analysis

FAULTY: The Assessment of Protein Content in an Unknown Sample

FAULTY: Egg White Protein Analysis

EXPLANATION: These titles leave the reader wondering what method of protein analysis was used and what sample was analyzed.

REVISION: Assessment of protein concentration in egg white using the biuret method

Here is another series of examples in which adding specific details improves the title from the first to the last example:

FAULTY: Study of an Enzymatic Reaction

EXPLANATION: Specify the variables you studied. Specify the enzyme and the substrate in the reaction.

FAULTY: Initial velocity of enzymatic reactions under varying conditions



EXPLANATION: Was *more than one* enzymatic reaction studied? What were the *specific conditions*? If you only studied one reaction, use the singular.

FAULTY: Study of 3 factors on an enzymatic reaction

EXPLANATION: What were the *specific factors*? Specify the enzyme and the substrate in the reaction.

FAULTY: Enzyme and substrate concentration and its effects on initial velocity as seen with peroxidase and hydrogen peroxide

EXPLANATION: The variables, the enzyme, and the substrate are present, but the sentence structure is a little awkward.

REVISION: Effect of substrate and enzyme concentration and hydroxylamine (an inhibitor) on the initial velocity of the peroxidase–hydrogen peroxide reaction

## Documenting Sources

Whenever you use another person's ideas, whether they are published or not, you must document the source. This is done by citing the source in an abbreviated form in the text (**in-text citation**) and then giving the full reference in the References section at the end of the paper (**end reference**). An exception to this practice is personal communications, which are cited in the text, but are not listed among the end references. Only sources that have been cited in the text may be included in the References section.

The CSE Manual (2006) recommends using the Citation-Sequence System (C-S), the Citation-Name System (C-N), or the Name-Year System (N-Y) for documenting your sources. The system you actually use depends on your instructor's preference or on the format specified by the particular scientific journal in which you aspire to publish.

In all three systems, the *in-text citation* is intended to be inconspicuous. A superscripted number or a number in parentheses (C-S and C-N systems) or authors' names and year (N-Y system) are minimally disruptive to the flow of the sentence. Contrast this style with the lengthy introduction practiced in some disciplines in the humanities: "According to Warne and Hickock in their 1989 paper published in *Plant Physiology*, antheridiogen may be related to the gibberellins." **Do not use this style in your lab reports!**

With regard to the *end reference*, the systems differ in the sequence of information and the listing of the month of publication. In the N-Y system, the year of publication follows the author's name; in the C-S and C-N systems, the year follows the journal name. The month of publication is only used in the C-S and C-N systems.

The Name-Year system has the advantage that people working in the field will know the literature and, on seeing the authors' names, will understand the in-text citation without having to check the end reference. With the Citation-Sequence and Citation-Name systems, the reader must turn to the reference list at the end of the paper to gain the same information. Regardless of which system you use, learn the proper way to format both the in-text citation and the end reference and use one system consistently throughout any given paper.

Finally, do not list sources in the end reference list, which you personally have not seen. If you feel that the original source is important enough to be cited, use the following approach:

Author (year) as cited by Author (year)



## *The Name-Year system*

The *in-text citation* consists of author(s) and year. The author(s) may be cited in parentheses at the end of the sentence or they may be the subject of the sentence, as shown in the following examples:

**TABLE 4.4** Number of authors determines how the authors are cited in N-Y system

| Number of Authors | Author as Subject | Parenthetical Reference (The comma between author[s] and year is optional.) |
|---|---|---|
| 1 | Author's last name (year) found that... | (Author's last name, year) |
| 2 | First author's last name and second author's last name (year) found that ... | (First author's last name and second author's last name, year) |
| 3 or more | First author's last name followed by and others or *et al.* (year) found that ... | (First author's last name and others, year) or *et al.* instead of *and others* |

*Note*: If you cite more than one paper published by the same author in *different* years, list them in chronological order: (Dawson 2001, 2003). If you cite more than one paper published by the same author in the *same* year, add a letter after the year: "...was described in recent work by Dawson (1999a, 1999b)."



**PARENTHESES:** C-fern gametophytes respond to antheridiogen only for a short time after inoculation (Banks and others 1993).

**AS THE SUBJECT:** Banks and others (1993) found that C-fern gametophytes respond to antheridiogen only for a short time after inoculation.

The **number of authors** determines how the *in-text citation* is written in the N-Y system (Table 4.4). For *one* author, write the author's last name and year. For *two* authors, write both authors' last names separated by the word *and* followed by the year. For *three or more* authors, write the first author's last name, the words *and others* (or *et al.*), and then the year.

In the *end references*, the sources are listed in **alphabetical order** according to the first author's last name. The format of the source determines which elements are included (Table 4.5). When there are 10 or fewer authors, list all authors' names. When there are more than 10 authors, list the first 10 and then write *et al.* or *and others* after the tenth name. Write each author's name in the form Last name First initials. Use a comma to separate one author's name from the next. Use a period only after the last author's name.

Examples of in-text citations and their corresponding end references are given in Table 4.6.

## *The Citation-Sequence system*

The *in-text citation* consists of a superscripted endnote (never a footnote) or a number in parentheses or square brackets within or at the end of the paraphrased sentence. The first reference cited is number 1, the second reference cited is number 2, and so on.

**SUPERSCRIPTED ENDNOTE:** There are four commonly used methods for determining protein concentration: the biuret method[1], the Lowry method[2], the Coomassie Blue (CB) dye-binding method[3], and the bicinchoninic acid (BCA) assay[4].

**PARENTHESES:** The Kjeldahl procedure is time-consuming and requires a large amount of sample (1, 2).

**BRACKETS:** Several review articles compare the advantages and disadvantages of these protein assays [5–10].

In the *end references*, the sources are listed in **numerical order** (in the order of citation). The format of the source determines which elements are

**TABLE 4.5** General format of two systems of source documentation used in scientific papers

| N-Y End Reference System | |
|---|---|
| The references are listed in **alphabetical order**. The last name is written first, followed by the initials. When there are 10 or fewer authors, list all authors' names. When there are more than 10 authors, list the first 10 and then write *et al.* or *and others* after the tenth name. Type references with hanging indent format. | |
| Journal article | First author's last name First initials, Subsequent authors' names separated by commas. Year of publication. Article title. Journal title Volume number(issue number): inclusive pages. |
| Article in book | First author's last name First initials, Subsequent authors' names separated by commas. Year of publication. Article title. In: Editors' names followed by a comma and the word *editors*. Book title, edition. Place of Publication: Publisher. pp inclusive pages. |
| Book | First author's or editor's last name First initials, Subsequent authors' or editors' names separated by commas. Year of publication. Title of book. Place of Publication: Publisher. Total number of pages in book followed by *p*. |

| C-S End Reference System | |
|---|---|
| The references are listed **in the order they are cited**. The author's last name is written first, followed by the initials. When there are 10 or fewer authors, list all authors' names. When there are more than 10 authors, list the first 10 and then write *et al.* or *and others* after the tenth name. | |
| Journal article | Number of the citation. First author's last name First initials, Subsequent authors' names separated by commas. Article title. Journal title Year Month; Volume number (issue number): inclusive pages. |
| Article in book | Number of the citation. First author's last name First initials, Subsequent authors' names separated by commas. Article title. In: Editors' names followed by a comma and the word *editors*. Book title, edition. Place of Publication: Publisher; Year of publication. pp inclusive pages. |
| Book | Number of the citation. First author's or editor's last name First initials, Subsequent authors' or editors' names separated by commas. Title of book. Place of Publication: Publisher; Year of publication. Total number of pages in book followed by *p*. |



included (Table 4.5). When there are 10 or fewer authors, list all authors' names. When there are more than 10 authors, list the first 10 and then write *et al.* or *and others* after the tenth name. Write each author's name in the form Last name First initials. Use a comma to separate one author's name from the next. Use a period only after the last author's name.

Examples of in-text citations and their corresponding end references are given in Table 4.6.

### The Citation-Name system

In the *end references*, the sources are listed in **alphabetical order** according to the first author's last name. The year and month of publication follow the journal name, as in C-S end reference format. The references are then numbered sequentially so that the first reference is number 1, the second reference is number 2, and so on. The *in-text citations* consist of superscripted endnotes (never footnotes) or a number in parentheses or square brackets within or at the end of the paraphrased sentence.

### Unpublished laboratory exercise

Unpublished material is usually not included in the References section. However, if your instructor asks that you cite laboratory exercises in your laboratory report, the *end reference* could look like this:

**C-S:** #. Author (omit if unknown). Title of lab exercise. Course number, Department, University. Year.

**N-Y:** Author (if unknown, replace with title of lab exercise). Year. Title of lab exercise. Course number, Department, University.

In N-Y format, the *in-text citation* for an unpublished lab exercise would include the author(s) and year, or, if the author is unknown, the title and year. The use of anonymous is not recommended (CSE Manual 2006).

### Personal communication

Unpublished information obtained during a discussion or by attending a lecture should be acknowledged when you use it in your lab report or scientific paper. The in-text citation includes the authority, the date, and the words "personal communication" or "unreferenced." For example:

> ...may be explained by possible contamination from viruses or bacteria (M. Pizzorno, personal communication, 2012 Oct 30).

It is **not necessary** to include personal communications in the references.

**TABLE 4.6 Examples of in-text citation and end reference format of two systems of source documentation used in scientific papers**

**Name-Year System**

| | |
|---|---|
| | **IN-TEXT CITATIONS** |
| 1 author<br>3 or more authors<br><br>2 authors<br>1 author | Gametophytes of the tropical fern *Ceratopteris richardii* (C-fern) develop either as males or hermaphrodites. Their fate is determined by the pheromone antheridiogen (Näf 1979; Näf and others 1975). Banks and others (1993) found that gametophytes respond to antheridiogen only for a short time between 3 and 4 days after inoculation. Although the structure of antheridiogen is unknown, it is thought to be related to the gibberellins (Warne and Hickok 1989). Gibberellins are a group of plant hormones involved in stem elongation, seed germination, flowering, and fruit development (Treshow 1970). |
| | **CORRESPONDING END REFERENCES** |
| Journal article | Banks J, Webb M, Hickok L. 1993. Programming of sexual phenotype in the homosporous fern *Ceratopteris richardii*. Inter. J. Plant Sci. 154(4): 522-534. |
| Article in book | Näf U. 1979. Antheridiogens and antheridial development. In: Dyer AF, editor. The Experimental Biology of Ferns. London: Academic Press. pp. 436-470. |
| Journal article | Näf U, Nakanishi K, Endo M. 1975. On the physiology and chemistry of fern antheridiogens. Bot. Rev. 41(3): 315-359. |
| Book | Treshow M. 1970. Environment and Plant Response. New York: McGraw-Hill. 250 p. |
| Journal article | Warne T, Hickok L. 1989. Evidence for a gibberellin biosynthetic origin of *Ceratopteris* antheridiogen. Plant Physiol. 89(2): 535-538. |



**TABLE 4.6** *Continued*

**Citation-Sequence System**

| | |
|---|---|
| | **IN-TEXT CITATIONS** |
| Sources are listed in the order they are cited | Gametophytes of the tropical fern *Ceratopteris richardii* (C-fern) develop either as males or hermaphrodites. Their fate is determined by the pheromone antheridiogen (1, 2). Gametophytes respond to antheridiogen only for a short time between 3 and 4 days after inoculation (3). Although the structure of antheridiogen is unknown, it is thought to be related to the gibberellins (4). Gibberellins are a group of plant hormones involved in stem elongation, seed germination, flowering, and fruit development (5). |
| | **CORRESPONDING END REFERENCES** |
| Article in book | 1. Näf U. Antheridiogens and antheridial development. In: Dyer AF, editor. The Experimental Biology of Ferns. London: Academic Press; 1979. pp. 436-470. |
| Journal article | 2. Näf U, Nakanishi K, Endo M. On the physiology and chemistry of fern antheridiogens. Bot. Rev. 1975 Jul-Sep; 41(3): 315-359. |
| Journal article | 3. Banks J, Webb M, Hickok L. Programming of sexual phenotype in the homosporous fern *Ceratopteris richardii*. Inter. J. Plant Sci. 1993 Dec; 154(4): 522-534. |
| Journal article | 4. Warne T, Hickok L. Evidence for a gibberellin biosynthetic origin of *Ceratopteris* antheridiogen. Plant Physiol. 1989 Feb; 89(2): 535-538. |
| Book | 5. Treshow M. Environment and Plant Response. New York: McGraw-Hill; 1970. 250 p. |

Book references give the total number of pages in the book, not the pages from which you extracted the information

### Internet sources

In the previous section you learned that the in-text citation and end reference format differs for journal articles, articles in a book, and books. These differences apply to both print and online publications. For a journal article, therefore, you should be able to locate on the website the names of the authors, a title, the journal name, a date of publication, the volume and issue number, and the extent (number of pages or similar). Besides this basic information, the CSE Manual (2006) recommends that you provide two additional items when your reference comes from the Internet: the URL (uniform resource locator) and the date accessed. For your lab reports, it is sufficient to treat references obtained online as print sources (unless your instructor tells you otherwise). If you would like to publish your work in a journal that adheres strictly to CSE guidelines, however, the following section shows the in-text citation and end reference format for an online journal article. For a comprehensive discussion of Internet citation formats along with many examples, see Patrias (2007).

> When URLs are used in text, they are enclosed in angle brackets (< >) to distinguish them from the rest of the text. (URLs can also be printed in color, in which case the angle brackets are not required.) Every character in a URL is significant, as are spaces and capitalization. Very long URLs can be broken before a punctuation mark (tilde ~, hyphen -, underscore _, period ., forward slash /, backslash \, or pipe |). The punctuation mark is then moved to the next line.

### Journal articles

The *in-text citation* for an online journal article is exactly the same as that for a printed journal article (see Table 4.6). A good approach for writing the *end reference* of an online journal article is to first locate the information you would need for a printed journal article, and then add the Internet-specific items (CSE Manual 2006). Choose one of the three systems—Name-Year, Citation-Sequence, or Citation-Name—and position the elements accordingly.

The general format for a *printed* end reference in the **Name-Year system**, including punctuation, is:

> Author(s). Date of publication. Title of article. Title of journal plus volume(issue): Inclusive page numbers

The corresponding format for an *online* reference, with the Internet information shown here in bold, is:



> Author(s). Date of publication. Title of article. Title of journal **[Internet]. [date updated; date cited]**; Volume(issue): Inclusive page numbers. **Available from: URL**

A screen shot of an online journal article web page is shown in Figure 4.11 and the elements required for citation are labeled. The corresponding end reference in **Name-Year format** with Internet-specific information is as follows:

> Wariishi H, Nonaka D, Johjima T, Nakamura N, Naruta Y, Kubo S, Fukuyama K. 2000. Direct binding of hydroxylamine to the heme iron of *Arthromyces ramosus* peroxidase. Substrate analogue that inhibits compound I formation in a competitive manner. J Biol Chem [Internet]. [cited 2012 Oct 29]; 275(42): 32919–32924. Available from: http://www.jbc.org/content/275/42/32919.long

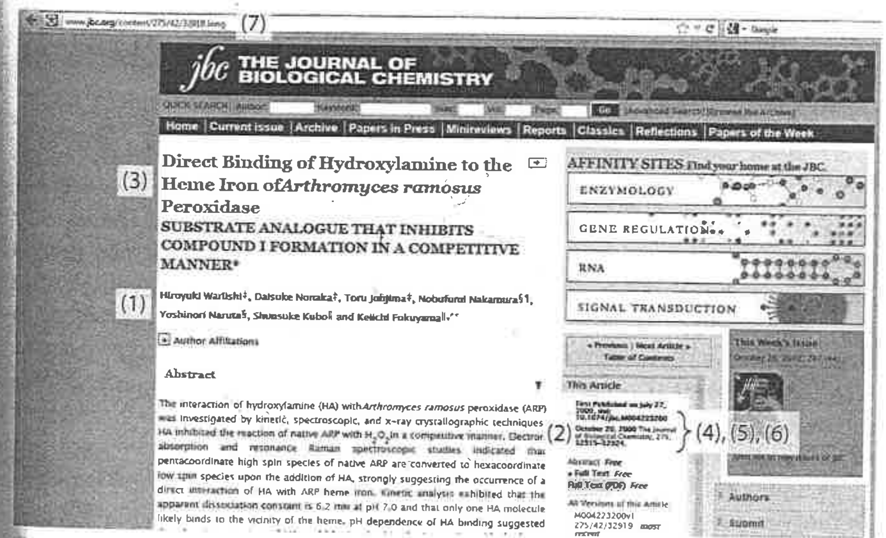



**Figure 4.11** Web page for an online journal article. The basic information needed to cite a journal article includes (1) authors, (2) date of publication, (3) article title, (4) journal title, (5) volume and issue number (if given), and (6) inclusive pages. In addition, for an online journal article, include (7) the URL and the date accessed in the end reference.

The general format for a *printed* reference in the **Citation-Sequence** system, including punctuation, is:

Number of the citation. Author(s). Title of article. Title of journal. plus year and month; Volume(issue): Inclusive page numbers,

The corresponding format for an *online* reference, with the Internet information shown here in bold, is:

Number of the citation. Author(s). Title of article. Title of journal **[Internet]**. Year and month **[date updated; date cited];** Volume(issue): Inclusive page numbers. **Available from: URL**

The end reference for the same online journal article shown in Figure 4.11 in **Citation-Sequence format** would be:

1. Wariishi H, Nonaka D, Johjima T, Nakamura N, Naruta Y, Kubo S, Fukuyama K. Direct binding of hydroxylamine to the heme iron of *Arthromyces ramosus* peroxidase. Substrate analogue that inhibits compound I formation in a competitive manner. J Biol Chem [Internet]. 2000 Oct [cited 2012 Oct 29]; 275(42): 32919–32924. Available from: http://www.jbc.org/content/275/42/32919.long

## Databases

A database is a collection of records with a standard format. Databases may be text-oriented or numerical and their content is usually accessed by means of a search box. You may cite an entire database if your goal is to make the reader aware of its existence, or you may only cite a part of the database to document an individual record. Some databases are available on paper and CD-ROM as well as on the Internet. Specify the medium, as Internet databases may contain more recent information than the corresponding paper or CD-ROM versions.

The general format for citing a database in the **Name-Year system** is:

Title of Database [medium designator]. Beginning date – ending date (if given). Edition. Place of Publication: Publisher. [date updated; date cited]. Available from: URL

To cite a database in the **Citation-Sequence system**, move the date after the publisher:

Number of the citation. Title of Database [Medium Designator]. Edition. Place of Publication: Publisher. Beginning date – ending date (if given). [date updated; date cited]. Available from: URL



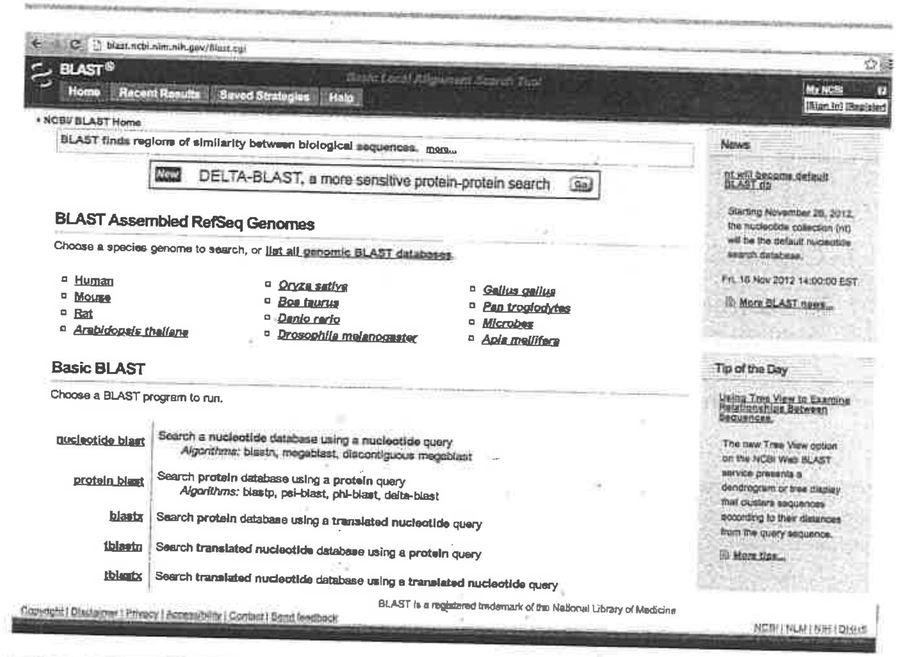



**Figure 4.12** Homepage for the National Center for Biotechnology Information's BLAST database. To search for a specific nucleotide sequence, use **nucleotide blast**, one of the databases within the BLAST database.

As an example, the homepage of the BLAST database is shown in Figure 4.12. The nucleotide blast, protein blast, blastx, tblastn, and tblastx databases are individual websites within the larger BLAST website. When citing websites within websites, the following rule applies: Always cite the most specific organizational entity that you can identify (Patrias 2007). Database titles do not always follow the rules of English grammar and punctuation. Because they are proper nouns, however, reproduce the title as closely as possible to the format on the screen (maintain upper or lower case letters, run-together words, etc.). Sometimes the information needed for the reference may be absent or hard to find. In this example, the beginning to ending dates and the edition of the database are not specified. The location of the place of publication and the publisher are not given on this page, but can be found by clicking the **Contact** link at the bottom of the page. Do your best to reference the source with the information provided.

A good faith attempt at citing the nucleotide blast database in **Name-Year format** would be as follows:

nucleotide blast [database on the Internet]. Bethesda (MD): National Library of Medicine (US), National Center for Biotechnology Information. [cited 2012 Oct 29]. Available from: http://blast.ncbi.nlm.nih.gov/Blast.cgi

In Citation-Sequence format:

1. nucleotide blast [database on the Internet]. Bethesda (MD): National Library of Medicine (US), National Center for Biotechnology Information. [cited 2012 Oct 29]. Available from: http://blast.ncbi.nlm.nih.gov/Blast.cgi

The *in-text citation* for a database in **Name-Year format** follows the same principles used for print publications (see Table 4.6) with a minor modifi- cation. The author is replaced with the title of the database and, when the date of publication is not known (as in the current example), the order of preference is the copyright date; the date of modification, update, or revi- sion; and the date cited (CSE Manual 2006). An example of an *in-text cita- tion* in **Name-Year format** for this database would be:

There was a 100% match between the DNA sequence of Sample 1 and the SV40 sequence in the NCBI databank (nucleotide blast database, 2012).

## Homepages

A homepage is the main page of a website, which provides links to differ- ent content areas of the site. Most of the information required to cite a web- site is found on the homepage. Make sure the organization or individual responsible for the website is reputable and, if possible, confirm informa- tion on the site using another source. The general format for citing a home- page in **Name-Year format** is:

Title of Homepage [Internet]. Date of publication. Edition. Place of publication: publisher; [date updated; date cited]. Available from: URL

To cite a homepage in **Citation-Sequence format**, move the date after the publisher:

Number of the citation. Title of Homepage [Internet]. Edition. Place of publication: publisher; date of publication [date updated; date cited]. Available from: URL



An example of a homepage is shown in Figure 4.13. All of the informa- tion required to cite this source is readily located. When the date of publi- cation is not specified, the order of preference is the copyright date; the date of modification, update, or revision; and the date cited (CSE Manual 2006). In this example, the copyright date, preceded by a lower case *c* is used in the end reference. The end reference in **Name-Year format:**

Stem Cells at the National Academies [Internet]. c2009. Washing- ton DC: National Academy of Sciences; [cited 2012 Oct 29]. Available from: http://dels-old.nas.edu/bls/stemcells/what- is-a-stem-cell.shtml

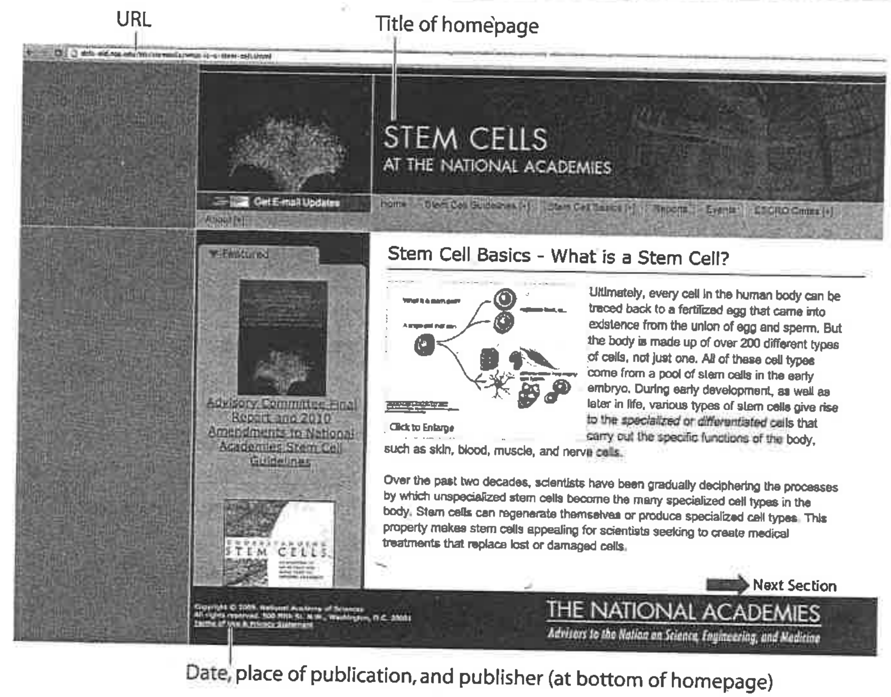



**Figure 4.13** The National Academies' website for information on stem cells. Well-constructed homepages make it easy to find the title, date, responsible organiza- tion, and place of publication.

The end reference in Citation-Sequence format:

1. Stem Cells at the National Academies [Internet]. Washington DC: National Academy of Sciences; c2009 [cited 2012 Oct 29]. Available from: http://dels-old.nas.edu/bls/stemcells/what-is-a-stem-cell.shtml

The *in-text citation* for a homepage in **Name-Year format** follows the same principles used for print publications (see Table 4.6) with a minor modification. The author is replaced with the title of the homepage. For the year, the order of preference is the date of publication; the copyright date; the date of modification, update, or revision; and the date cited (CSE Manual 2006).

### *Emails and discussion lists*

Electronic mail (email) and discussion lists (LISTSERVs, news groups, bulletin boards, etc.) are usually considered to be a form of personal communication (see p. 85). Information obtained through personal communication is cited in the in-text citation, but not in the end reference list. The in-text citation should include the name of the authority, the date, and the words "personal communication" or "unreferenced" to indicate that the citation is not listed in the References section.

Chapter 5

# REVISION

Revision—reading your paper and making corrections and improvements—is an important task that usually does not get nearly the attention it deserves. Too many students write the first draft of their laboratory report the night before it is due and hand in the hard copy, still warm from the printer, without even having proofread it.

The truth is, most writers cannot produce a clear, concise, and error-free product on the first try. It may take several revisions before the writer is satisfied that he or she has conveyed, with clarity and logic, the motivation for writing the paper, the important findings, and the conclusions. Do not try to write and revise your entire paper in one "marathon" session. Instead, **break up the writing process** into multiple, shorter segments. The breaks give your mind time to process what you've written, get help if necessary, get feedback from your peer reviewer, and make final revisions.

Most excellent writers were not born that way. They achieved excellence through "deliberate practice" (Martin 2011). The old adage "practice makes perfect" applies not just to musicians and athletes, but to *you* as an aspiring author in the biological sciences. So if writing doesn't come naturally to you, take heart. Writing laboratory reports becomes easier with practice, especially if you learn from your mistakes.

## Getting Ready to Revise

### *Take a break*

The first step in revision is *not* to do it immediately after you have completed the first draft. You need to distance yourself from the paper to gain the objectivity needed to read the paper critically. So take a break, and go for a run or get a good night's sleep.