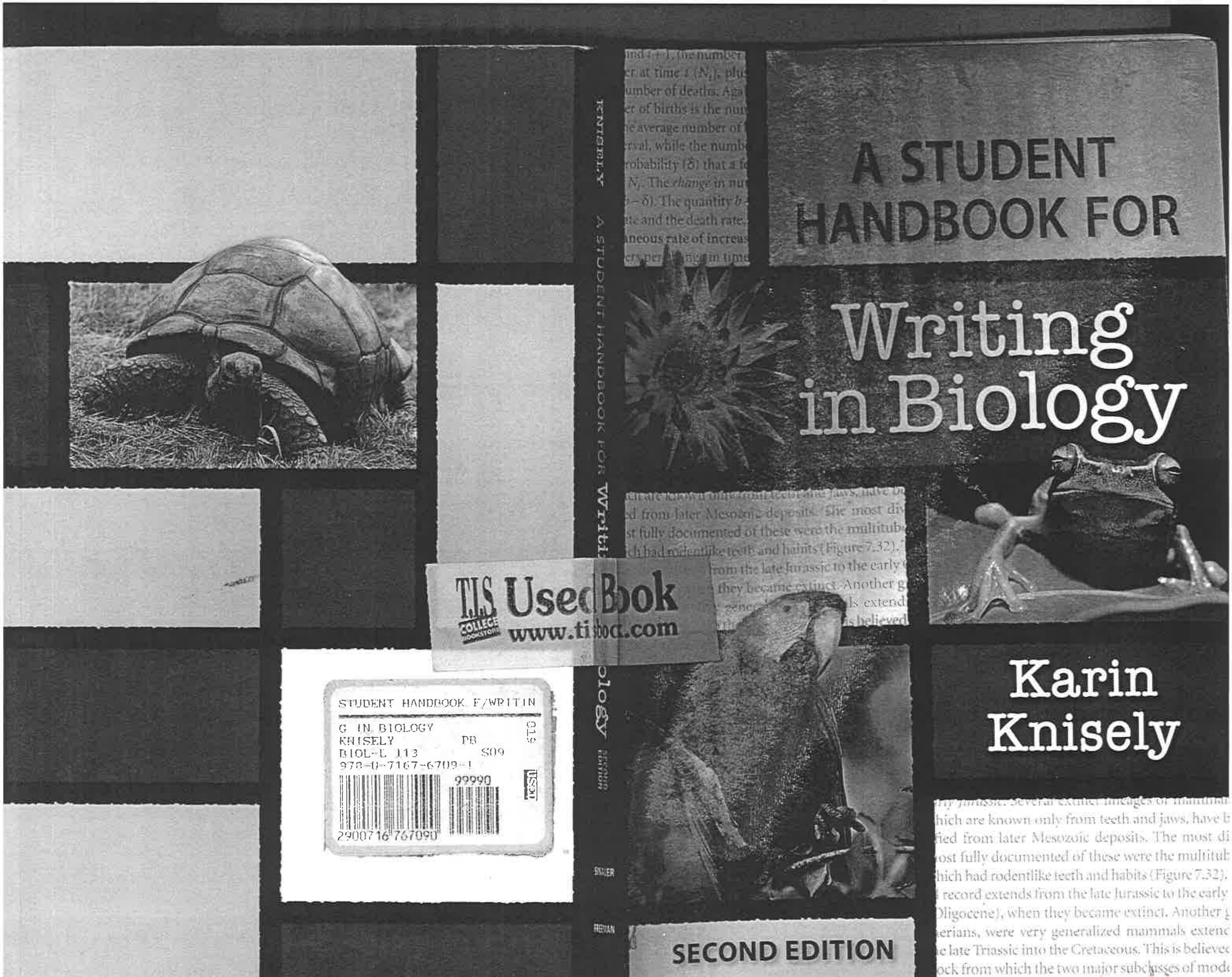
A STUDENT HANDBOOK FOR
Writing in Biology
Karin Knisely
SECOND EDITION
KNISELY A STUDENT HANDBOOK FOR Writing in Biology SECOND EDITION
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FREEMAN
T.I.S. Used Book
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You should think about your reputation even as a student. When you write your laboratory reports in an accepted, concise, and accurate manner, your instructor knows that you are serious about your work. Your instructor appreciates not only the time and effort required to understand the subject matter, but also your willingness to write according to the standards of the profession.

Model Papers

Before writing your first laboratory report, go to the library and take a look at some biology journals such as *American Journal of Botany, Ecology, The EMBO Journal, Journal of Biological Chemistry, Journal of Molecular Biology,* and *Marine Biology*. Photocopy one or two journal articles that interest you so you can refer to them for format questions.

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 left margin 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 proofreading and 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 "Look at the Big Picture" 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.

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 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.

TABLE 4.1 *Continued*

TIME FRAME	ACTIVITY	RATIONALE
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," 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!).

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 <www.sinauer.com/Knisely> 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 "Formatting a Document" 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 Basics" and Appendix 2 "Making XY Graphs in Excel." If there is a task that is not covered in these appendices, write it down and ask an expert later. If you run into a major

TABLE 4.2 Instructions to authors of laboratory reports

FEATURE	LAYOUT
Paper	8½" x 11" (or DIN A4) white bond, one side only
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.
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.
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.

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. Images generally require more storage space than text, which means that large files may not fit on a floppy disk; use a zip disk or CD instead, or use a jump drive to transfer files from one computer to another via the USB port.

Save your file frequently while writing your paper. Set up your computer to automatically save data every 10 minutes, so that in the event of a power failure you will have lost only 10 minutes' worth of work. These tasks are described in Appendix 1.

Install antivirus software on your computer, and always check disks and CDs for viruses before you use them. Beware of files attached to e-mail messages. Do not open attachments unless you are sure they come from a reliable source.

Store floppy disks, zip disks, and CDs in protective boxes. Keep them away from magnetic devices (TV, speakers, etc.) and excess humidity, heat, and cold.

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. Restricting the time to 1 hour forces you to make effective use of limited time. It also takes advantage of the attention span to which you are accustomed in lecture.

If your paper is progressing well and you are having fun, extend the 1-hour period until you perceive a loss of concentration. Promise yourself a reward after a certain amount of progress. It is not necessary to deprive yourself of pleasure as long as you work efficiently.

Reread the Laboratory Exercise

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

Audience and Tone

Scientific papers are written for scientists. Similarly, laboratory reports are intended to describe procedures and findings to fellow students. Of course, your instructor is going to read and evaluate your laboratory report, but your instructor is not the audience for whom you are writing. You are *writing for your peers*—students just like yourself.

Write as though your peers are fellow scientists, not students in a classroom situation. Note the difference between the original text and the revision in the following examples:

EXAMPLE 1: 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.

EXAMPLE 2: 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.

Your audience has a knowledge base similar to your own. Thus, when you introduce your topic and describe and interpret your results, you should assume that your audience will know some scientific vocabulary, but you should clarify or define less familiar terms. When deciding on how much background information to include, assume that your audience knows what you learned in class.

Keep the tone of your laboratory report factual and objective. Do not use jargon (terms known only to experts) or copy information verbatim from journal articles or your textbook. Remember that your objective is to write for your peers in a style that they can understand clearly.

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.

Writing Style

Laboratory *exercises* are typically written in present tense, often with instructions in the form of a numbered list. When you write your laboratory *report*, however, summarize what you did in **full sentences and well-developed paragraphs**. Use **past tense**, because you completed the experiment some time ago.

You will have to make decisions on verb voice when you describe the procedure. For example:

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." When you describe a procedure, *who* did it is not as important as *what* was done. Passive voice places the emphasis on the potatoes, where it belongs. Take care not to overuse passive voice, however, because it can make your writing seem stuffy and impersonal. See the section "Active and Passive Voice" in Chapter 5 for appropriate use of active and passive voice.

Details: To Include or Not To Include?

When you first begin to write scientific papers, it may be hard to decide how much detail to include in the Materials and Methods section. On the one hand, too many details bore the reader; on the other hand, you must include enough information to allow the reader to repeat the experiment. The following are some examples of things to avoid and include in Materials and Methods sections.

Avoid listing materials. The separation of the heading "Materials and Methods" into two parts is understandably confusing for beginning students. The implication is that the materials should be listed separately from the methods. In fact, **materials should not be listed separately** unless the strain of bacteria, vector (plasmid), growth media, or chemicals was obtained from a special or noncommercial source. It will be obvious to the reader what materials are required on reading the methods.

Avoid any reference to the container. Consider the following example:

EXAMPLE: 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.

There are two problems with this passage: (1) It is not necessary to mention that clean, suitable containers were used to store the solutions; this is common practice in the laboratory. (2) The contents are more important than the label and the appropriate units must be mentioned.

REVISION: The following hydrogen peroxide solutions were prepared: 0, 0.1, 0.2, 0.5, 0.8, 1.0, 5.0, and 10.0%.

Avoid lengthy descriptions of routine procedures. Your peers have learned certain basic laboratory techniques, such as using an electronic balance to weigh chemicals, a vortex mixer to mix solutions, a spectrophotometer to measure absorbance (optical density) of solutions, and micropipettors to measure small volumes. The amount of detail in the following examples is therefore unnecessary.

EXAMPLE: 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.

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

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

EXAMPLE: 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.

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

Avoid giving "previews" of your data analysis in the Materials and Methods section. Consider the following passage:

EXAMPLE: 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.

Making graphs is something that you do when you summarize 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.*

Include all relevant information needed to repeat the experiment. Consider the following example:

EXAMPLE: 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.

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 are left out.

REVISION: 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.

Cite published sources. If you are paraphrasing a published laboratory exercise, it is necessary to cite the source (see "Documenting Sources"). 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 findings presented in the visuals.

Describe the findings in an objective manner, without explaining why or discussing possible implications.

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 are interested in whether the data support or negate your hypotheses.
- **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 "Organizing Your Data."
- **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 parenthetically.** You should first describe what 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.

Tips for Writing the Body of the Results Section

Specify the visual that contains the data that you are describing. Refer to Figure 4.1 as you read the following passage:

> EXAMPLE: 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%.

This passage is unsuitable because we don't know where to find the results the author is describing. Always refer to the visual parentheti-

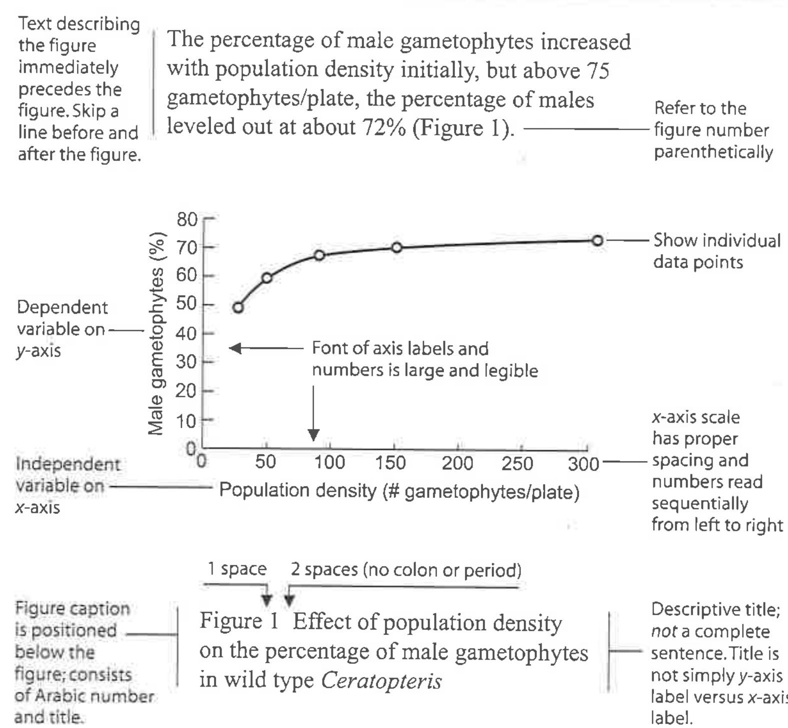


Figure 4.1 Excerpt from a Results section showing a properly formatted figure with one line (data set); text that describes the figure precedes it

cally so that the reader can look at the visual presentation of the data while reading the author's description of those data.

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).

Eliminate unnecessary introductions. Look at Figure 4.2 as you read the following example:

EXAMPLE: Table 1 shows the effects of light and hormones on the germination of light-sensitive lettuce seeds. One group of seeds was treated with ABA and left under a fluorescent light, while another group received GA in the dark. It can be seen that the majority of the seeds (92.5%) germinated in the light, but fewer germinated in the light when ABA was present.

The first sentence of this passage is unnecessary, because **it says nothing substantive about the data contained in Table 1**; instead, it describes the layout of the table, which needs no description. The second sentence is also unnecessary, because it restates the materials and methods, but says nothing about the results. The first part of the third sentence ("It can be seen that") is simply verbiage.

Avoid other unnecessary introductions such as:

- It was found that…
- When the test plates were observed and counted, …
- There is also a general trend where…
- It can be determined that…
- Table 1 shows that there is a relationship between hormones and seed germination. (*What* is the relationship?)

Scientific writing is concise and to the point. When you write the body of the Results section, eliminate unnecessary introductions. Instead, jump right in with a substantive observation. Write in past tense, because in scientific writing, present tense denotes that the statement is a generally accepted fact (see "Present Tense or Past Tense?" in Chapter 5). It remains to be seen if your results are accepted by the scientific community!

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.

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

Refer to the table number parenthetically

Arabic number

1 space

2 spaces (not colon or period)

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

Descriptive title; not a complete sentence. Essence of table can be understood without referring to the body of the Results section.

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

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

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

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

REVISION: The majority of the seeds (92.5%) germinated in the light, but fewer seeds germinated when they were exposed to 0.05-8 μM ABA (Table 1).

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, drawings, gel photos, X-ray images, and microscope images are all called *figures* in scientific papers.

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 "Organizing Your Data," Example 1).

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.

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.

Titles consist of a precise noun phrase, not a complete sentence, and only the first word and proper nouns are capitalized. The reader should be able to understand the essence of the table without having to refer to the body (the text) of the Results section.

FAULTY: Table 1 Table of interaction between light and hormones in the germination of light-sensitive lettuce seeds [Do not start a title for a visual with a description of the visual.]

FAULTY: Table 1 Seed germination data [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). Mention 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 Appendix 1, Section 2.12) or Microsoft Excel (see "Importing Tables Into Microsoft Word" in Appendix 2).

Line graphs. Line graphs (or XY graphs) are perhaps the most frequently used type of graph in biology. Line graphs are used to display a trend or an important relationship between one or more variables. The data displayed in line graphs are **continuous and numerical**.

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. The data then show the effect of x on y, or y as a function of x.

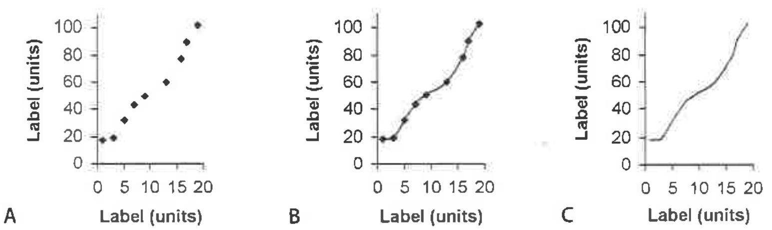
There are a number of formats for plotting data on an XY graph (Figure 4.3). Situations in which each format might be used are given.

Figures are always numbered and titled *beneath* the visual (see Figures 4.1 and 4.4). 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.

Figure titles should consist of a precise noun phrase, not a complete sentence, and only the first word and proper nouns are capitalized. The reader should be able to understand the title without referring to the text in the Results section.

FAULTY: Figure 1 Percentage of male gametophytes vs. population density [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* [Separate the figure number and the title.]



A

Format: Data points, no connecting line

Uses: As a preliminary display before deciding on a better alternative; to emphasize variability in the data

B

Format: Data points connected by a smoothed line

Uses: To describe the physical phenomena represented by a few data points; contains an element of prediction

C

Format: Smoothed line without data points

Uses: Never use this format to present experimental data, because the actual data are not shown. This format might be used to present the results of calculations.

Figure 4.3 Different formats for XY graphs

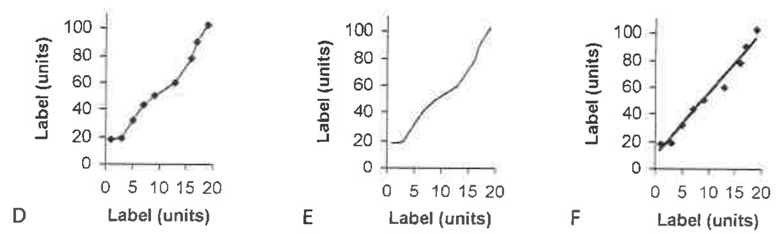
FAULTY: Figure 1 Line graph of the effect of population density on the percentage of male gametophytes in wild type *Ceratopteris* [Do not start a title for a visual with a description of the visual.]

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



D

Format: Data points connected by straight lines

Uses: To describe the physical phenomena represented by a few data points. In some disciplines, by connecting the points with straight lines, the author indicates that he or she makes no assumptions about the behavior of the system between the measured points.

E

Format: Straight lines without data points

Uses: Never use this format to present experimental data, because the actual data are not shown. This format might be used to present the results of calculations without smoothing.

F

Format: Data points connected by a trendline

Uses: (1) To determine if there is a correlation between two variables; (2) To predict one variable when the other is known (e.g., standard curve)

Figure 4.3 *Continued*

- 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.

Figures in your laboratory report should be prepared according to the guidelines specified by the Council of Science Editors (CBE Manual, 1994). 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.

Bar graphs. A bar graph allows you to compare individual sets of data when these data are **non-numerical or discontinuous**—this is the main difference between line graphs and bar graphs. For example, if you wanted to compare the final height of the same species of plant treated with four different nutrient solutions (Figure 4.5), each bar could be used to represent the plants treated with one nutrient solution. The data

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).

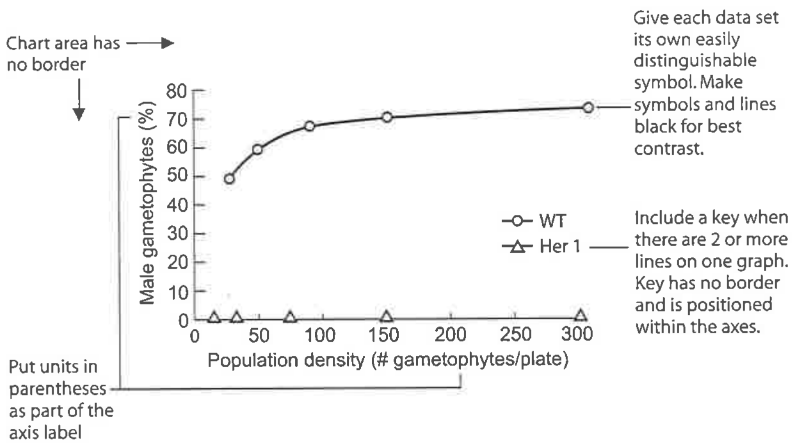


Figure title is a descriptive phrase — Figure 2 Effect of population density on the percentage of male gametophytes in wild type and Her 1 *Ceratopteris* — Italicize Latin names of genera

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.

plotted on the x-axis are non-numerical, because different nutrient solutions (not numbers) are being compared. The data are discontinuous, because the individual solutions have no effect on the growth of the plants treated with the other nutrient solutions.

Bar graphs can be arranged either vertically (Figure 4.5, also called a column graph) 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

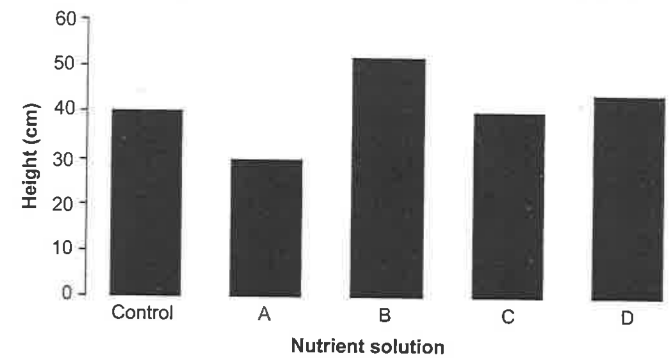


Figure 4.5 Final height of corn plants after 4-week treatment with different nutrient solutions. This figure is an example of a column graph.

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).

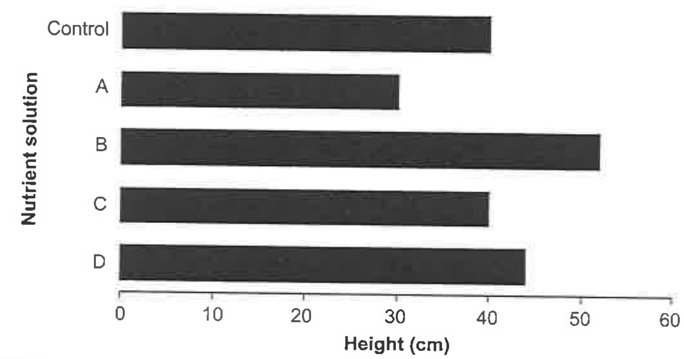


Figure 4.6 Final height of corn plants after 4-week treatment with different nutrient solutions. This figure is an example of a horizontal bar graph.

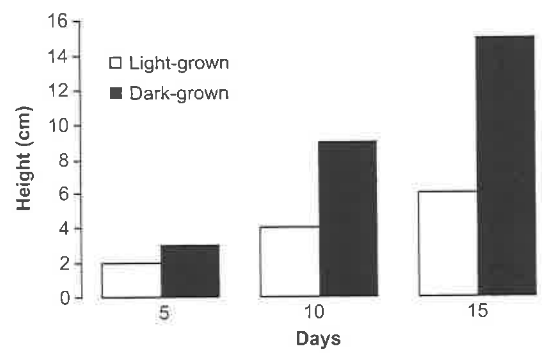


Figure 4.7 Difference in height of groups of light-grown and dark-grown bean seedlings at 5, 10, and 15 days after planting. This figure is an example of a clustered bar graph. Each bar in the cluster must be easily distinguishable from its neighbor.

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.

Organizing Your Data

Reread the questions in the laboratory exercise to determine what your instructor expects you to learn from the data. You may also find specific instructions on how to organize the data (tables, line graphs, bar graphs, etc.). Based on these expectations, decide which visual is best. 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**.

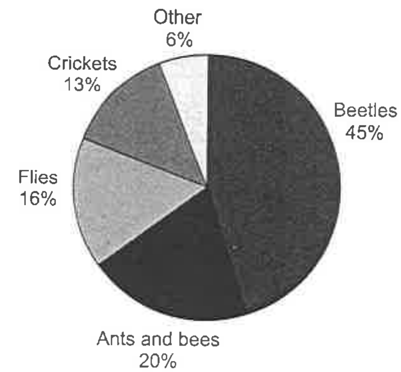


Figure 4.8 Composition of insects in backyard survey. Pie graphs are used to show data as a percentage of the total data.

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.

(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)

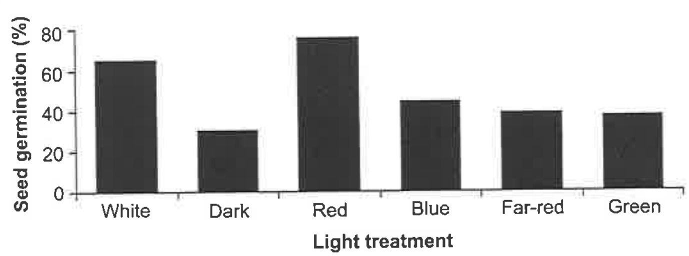


Figure 1 Effect of light treatment on percentage of light-sensitive lettuce seeds germinated after 30 hr

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).

POSSIBLE SOLUTION: Since some of the data are qualitative 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.

INAPPROPRIATE: A *line graph* is **not** appropriate because the exact wavelengths of light to which the seeds were exposed are not known. *Text only* is **not** appropriate because listing the seed germination percentages in a sentence is tedious to read and hard to comprehend.

EXAMPLE 3: Blackworms were exposed to different concentrations of a caffeine solution for 15 minutes. The pulsation rate of the dorsal blood vessel was measured before and after treatment and the raw data were expressed as percent change in pulsation rate (negative if the rate decreased and positive if it increased).

POSSIBLE SOLUTION: Whenever *different concentrations* of the same drug,hormone, or solution are tested, think **dose-response curve**. A dose-response curve is a *line graph* that depicts the dose (independent variable) on the *x*-axis and the response (dependent variable) on the *y*-axis (Figure 4.10). The data points were purposely not connected to show variability in pulsation rate at the same concentration of caffeine (due to variability among blackworms or variability among student measurement of pulsation rate).

EXAMPLE 4: 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 4.11).

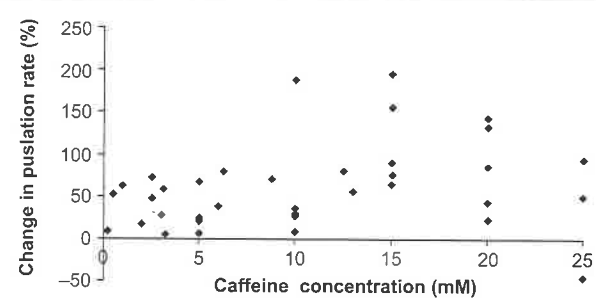


Figure 4.10 Effect of caffeine on pulsation rate of blackworms. When the data points are not connected in order to show variability, the line graph may also be called a scatter plot.

(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	0.04
60	0.007
70	0
100	0

(B)

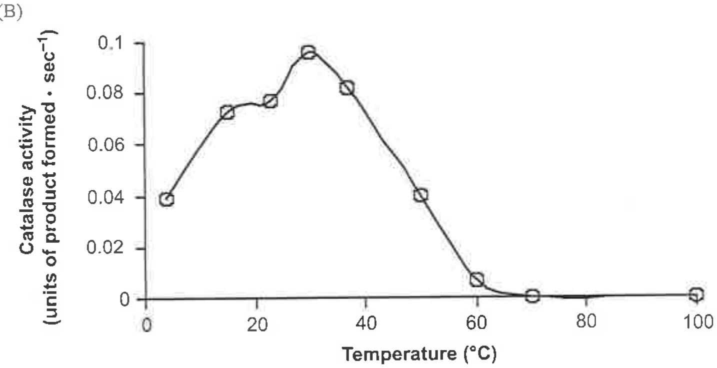


Figure 1 Effect of temperature on catalase activity

Figure 4.11 Example 4 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.

Standard curves. Standard curves represent a *special case of line graph* in which the goal of the analysis is to predict one variable when the other is known. At first the data points are plotted as a scatter plot, and then a linear regression line (trendline) is fitted to the points. The degree to which the trendline actually fits the data is given by the *R*-squared value, whereby the closer the *R*-squared value is to 1, the better the correlation or fit.

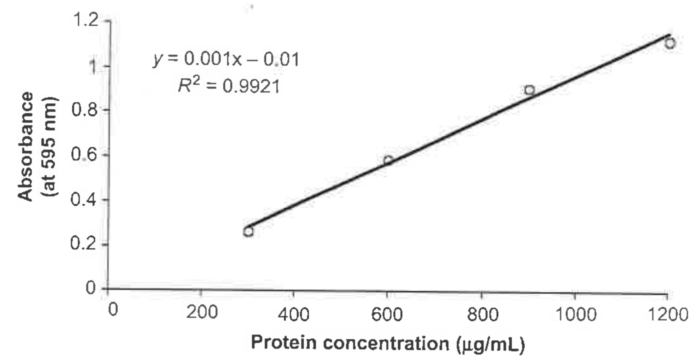


Figure 4.12 Bradford standard curve constructed with absorbance data for known concentrations of BSA. The R^2 value indicates that the linear regression line fits the data very well. The absorbance of a solution with unknown protein concentration is then measured, and the absorbance is substituted into the regression equation for y to determine x (protein concentration).

To make a standard curve for a protein assay, such as the Biuret assay or the Bradford assay, a scientist prepares known concentrations of a standard protein solution (such as bovine serum albumin) and then measures the absorbance of each solution using a spectrophotometer. The relationship between absorbance and concentration is expected to be linear (Figure 4.12), as expressed in Beer's law.

To predict the protein concentration in an "unknown" solution, the scientist measures the absorbance of the solution, and then predicts the protein concentration using the regression equation of the standard curve.

Think Ahead to the Discussion

As you describe the important findings of your investigation, think about what you already know about the subject. Are the results expected? Do they agree with the findings of other investigators?

- If yes, then you can jot down your ideas to use in the Discussion section.
- If no, try to develop possible explanations for the results. Some reasons to consider are:
  - Human error (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 influenced your results, it is important to 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. Furthermore, informal discussions may help you clarify what you know and what you do not know about the topic.

Equations

Equations are neither tables nor figures. They should be 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 other) section, number each equation sequentially and place the number in parentheses on the right margin. For example:

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

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 absorbance value was substituted for y, and the equation was solved for x (the protein concentration):
>
> $$\begin{aligned} y &= 0.0417x \\ 0.225 &= 0.0417x \\ 5.40 &= x \end{aligned}$$
>
> Thus, the protein concentration of the sample was 5.40 mg/mL.

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 and explain why they are important**. For a strong Discussion section:
- Summarize the results in a way that provides evidence for your conclusions. Avoid using the word "prove" when discussing your results:

  FAULTY: These results prove that my hypothesis is correct.

  REVISION: These results provide support for my hypothesis.
- State how your results relate to existing knowledge (cite literature sources).
- Point out any inconsistencies in your data. This is preferable to concealing an anomalous result.
- Discuss possible sources of error.
- Describe future extensions of the current work.

Write the Introduction

The Introduction concisely states what motivated the study, how it fits into the existing body of knowledge, and the objectives of the work. The introduction consists of two primary parts: (1) background information from the literature and (2) objectives of the current work.

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

If you designed your own experiment based on the scientific method, you probably answered these questions already. If this investigation was a laboratory exercise prepared by your instructor, reread the exercise to see if some of these questions have already been answered. The idea is not to copy the laboratory exercise introduction verbatim, but to make sure you understand the objectives.

Use keywords from the objectives to locate background information in the literature (see Chapter 2). Evaluate the titles in the "hits" critically to make sure the sources are relevant to your investigation.

The opening sentence of the Introduction section is usually a general observation or result familiar to the audience. By convention, generally accepted statements are written in present tense (see "Present Tense or

Past Tense?" in Chapter 5). Subsequent sentences narrow down the topic to the specific focus of the current investigation. 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 past tense in the last paragraph of the Introduction section.

Effective Advertising

The whole point of writing your paper is to communicate your work to your peers. The Abstract and the Title are the primary tools your audience 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 the reader 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 nondescriptive titles:

FAULTY: Quantitative Protein Analysis

FAULTY: The Assessment of Protein Content in an Unknown Sample

FAULTY: Egg White Protein Analysis

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

Documenting Sources

References are typically cited in the Introduction and Discussion sections of a scientific paper, and the procedures given in Materials and Methods are often modifications of those in previous work. Citation and reference format in the sciences differs from that in the humanities in two important ways:

- It is not customary to use direct quotations in scientific papers; paraphrase instead.