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The Scientific Method

Trying to understand natural phenomena is human nature. We are curious about why things happen the way they do, and we expect to be able to understand these events through careful observation and measurement. This process is known as the scientific method, and it is the foundation of all knowledge in the biological sciences.

An Introduction to the Scientific Method

The scientific method involves a number of steps:

- Asking questions
- Looking for sources that might help answer the questions
- Developing possible explanations (hypotheses)
- Designing an experiment to test a hypothesis
- Predicting what the outcome of an experiment will be if the hypothesis is correct
- Collecting data
- Analyzing data
- Developing possible explanations for the experimental results
- Revising original hypotheses to take into account new findings
- Designing new experiments to test the new hypotheses (or other experiments to provide further support for old hypotheses)
- Sharing findings with other scientists

Most scientists do not rigidly adhere to this sequence of steps, but it provides a useful starting point for how to conduct a scientific investigation.

Ask a question

As a biology student, you are probably naturally curious about your environment. You wonder about the *hows* and *whys* of things you observe. To apply the scientific method to your questions, however, the phenomena of interest must be sufficiently well defined. The parameters that describe the phenomena must be measurable and controllable. For example, let's say that you learned that:

Dwarf pea plants contain a lower concentration of the hormone gibberellic acid than wild-type pea plants of normal height.

You might ask the question:

Does gibberellic acid regulate plant height?

This is a question that can be answered using the scientific method, because the parameters can be controlled and measured. On the other hand, the following question could not be answered easily with the scientific method:

Will the addition of gibberellic acid increase a plant's sense of well-being?

In this example, "a sense of well-being" is not something that can be measured or controlled.

Look for answers to your question

There is a good chance that other people have already asked the same question. That means that there is a good chance that you may be able to find the answer to your question, if you know where to look. Secondary references such as your textbook, encyclopedias, and information posted on the websites of university research groups, professional societies, museums, and government agencies are usually easier to comprehend than journal articles and may be good places to begin finding answers (see the section "Understand your topic" in Chapter 2). Curiously, attempts to answer the original question often result in new questions, and unexpected findings lead to new directions in research. By reading other people's work, you may think of a more interesting question, define your question more clearly, or modify your question in some other way.

Turn your question into a hypothesis

As a result of your literature search or conversations with experts, you may now have a tentative answer to your original (or modified) question.

Now it is time to develop a hypothesis. A hypothesis is a possible explanation for something you have observed. **You must have information before you can propose a hypothesis!** Without information, your hypothesis is nothing more than an uneducated guess. That is why you must look for possible answers before you can turn your question into a hypothesis.

A useful hypothesis is one that can be tested and either supported or negated. A hypothesis can never be *proven* right, but the evidence gained from your observations and/or measurements can *provide support* for the hypothesis. Thus, when scientists write papers, they never say, "The results prove that..." Instead, they write, "The results suggest that..." or "The results provide support for..."

You might transform your question "Does gibberellic acid regulate plant height?" into the following testable hypothesis:

Good: The addition of gibberellic acid to dwarf plants will allow them to grow to the height of normal, wild-type plants.

This hypothesis provides specific expectations that can be tested. In contrast, the following hypothesis is not specific enough:

Vague: The addition of gibberellic acid will affect the height of dwarf plants.

Design an experiment to test your hypothesis

In an **observational study**, scientists observe individuals and measure variables of interest without trying to control the variables or influence the response. While observations provide important information about a group, it is difficult to draw conclusions about cause and effect relationships because multiple factors affect the response. That's the main reason why scientists conduct experiments. Experiments are studies in which the investigator imposes a specific treatment on a person or thing while controlling the other factors that might influence the response.

The first step in designing an experiment is to determine which variables might be influential. Of those variables, only one may be manipulated in any given experiment; the others have to remain constant. The individuals in the experiment are then divided into treatment and control groups. The treatment group is subjected to the independent variable and the control group is not; all other conditions are the same for the two groups. If the hypothesis is supported, the individuals in the treatment group will respond differently from those in the control group. If there is no difference in response between the treatment and control groups, the so-called **null hypothesis** is supported. Having enough replicates lends assurance that the results are reliable.

Define the variables Variables are commonly classified as independent or explanatory variables, dependent or response variables, and controlled variables. The *one* variable that a scientist manipulates in a given experiment is called the **independent variable** or the explanatory variable, so called because it “explains” or influences the response. It is important to manipulate *only one* variable at a time to determine whether or not a cause and effect relationship exists between that variable and an individual’s response. The other variables that may affect the response must be carefully controlled so that they do not confound the relationship between the independent variable and the dependent variables.

Dependent variables are those affected by the imposed treatment; in other words, they represent an individual’s response to the independent variable. Dependent variables are variables such as size, number of seeds produced, and velocity of an enzymatic reaction, which can be measured or observed.

The hypothesis proposed earlier involves testing whether there is a cause and effect relationship between gibberellic acid (GA) treatment and plant height. GA level is the variable that will be manipulated; plant height is the response that we’ll measure. Because plant height is affected by many other factors such as ambient temperature, humidity, age of the plants, day length, amount of fertilizer, and watering regime, however, we must keep these controlled variables constant so that any differences in response can be attributed to the GA treatment.

Set up the treatment and control groups The individuals in the experiment are assigned randomly to either a treatment group or a control group. Those in the treatment group will be subjected to the independent variable (GA in this case), while those in the control group will not. Depending on the hypothesis, the control group may be subdivided into positive and negative controls. Negative controls are not treated with the independent variable and are not expected to show a response. Positive controls represent a reference for treatment groups that demonstrate a response consistent with the hypothesis.

HYPOTHESIS: Adding GA to dwarf plants will allow them to grow to the height of normal, wild-type plants.

TREATMENT GROUP: Dwarf plants + GA

CONTROL GROUPS:

NEGATIVE: Dwarf plants + no GA (substitute an equal volume of water)

POSITIVE: Wild-type plants + no GA

Determine the level of treatment for the independent variable How much GA should be added to the dwarf plants in the treatment group to produce an increase in height? Too little GA may not effect a response, but too much might be toxic. To determine the appropriate level of treatment, consult the literature or carry out a preliminary experiment. The level may even be a range of concentrations that is appropriate for the biological system.

Provide enough replicates A single result is not statistically valid. The same treatment must be applied to many individuals and the experiment must be repeated several times to be confident that the results are reliable.

Make predictions about the outcome of your experiment Predictions provide a sense of direction during both the design stage and the data analysis stage of your experiment. For each treatment and control group, predict the outcome of the experiment if your hypothesis is supported. You may also choose to state the null hypothesis, which is that the treatment has no effect on the response.

HYPOTHESIS: Adding GA to dwarf plants will allow them to grow to the height of normal, wild-type plants.

TREATMENT GROUP: Dwarf plants + GA

PREDICTION IF HYPOTHESIS IS SUPPORTED: Dwarf plants will grow as tall as wild-type plants + no GA.

NULL HYPOTHESIS: Dwarf plants will not grow to the height of wild-type plants.

NEGATIVE CONTROL: Dwarf plants + no GA

PREDICTION: Dwarf plants will be short.

POSITIVE CONTROL: Wild-type plants + no GA

PREDICTION: Wild-type plants will be tall.

Record data

Scientists record procedures and results in a laboratory notebook. The type of notebook (bound or loose leaf, with or without duplicate pages) may be prescribed by your instructor or the principal investigator of the research lab. More important than the physical notebook, however, is the detail and accuracy of what’s recorded inside. For each experiment or study, include the following information:

- Investigator's name
- The date (month, day, and year)
- The purpose
- The procedure (in words or as a flow chart)
- Numerical data, along with units of measurement, recorded in well-organized tables
- Drawings with dimensions and magnification, where appropriate. Structures are drawn in proportion to the whole. Parts are labeled.
- Observations about the appearance, color, texture, and so on are included.
- Graphs, printouts, and gel images
- Calculations
- A brief summary of the results
- Questions, possible errors, and other notes

When deciding on the level of detail, imagine that, years from now, you or someone else wants to repeat the experiment and confirm the results. The more information you provide, the easier it will be to understand what you did, what problems you encountered, suggestions for improving the procedure, the results you obtained, how you summarized the data, and how you reached your conclusions.

Summarize numerical data

The raw data in lab notebooks are the basis for the results published in the primary and secondary literature. Published results, however, usually represent a *summary* of the raw data by the author, who is both knowledgeable about the subject and intimately familiar with the experiment. We rely on the author's experience and integrity to reduce the original data to a more manageable form that is an honest representation of the phenomenon and which lends itself to interpretation.

How the author presents data in the Results section depends in part on the scope of the question asked at the beginning. Broad questions about a population involve **statistical inference**, whereby results from a sample or subset of the population are applied to the whole. Because a different sample may produce different results, the author includes a statement about the reliability of his or her conclusions using appropriate statistical language. On the other hand, narrower questions about a specific situation may be answered from the data at hand. For example, questions such as "Which fraction of a purification procedure contains the most enzymatic activity?" or "Which medium produces the highest concentration of bacteria?" can be answered from the collected data and require no

inference about a larger population. When the data are consistent from one experiment to the next, scientists gain confidence that their conclusions are valid.

When you are given the task of summarizing the raw data, first distinguish between trustworthy and erroneous data. Erroneous data include results obtained by dubious means, for example, by not following the procedure, using the equipment improperly, or making simple arithmetic errors. Trustworthy data include results obtained legitimately, but which may still have quite a bit of unexplained variability. If time permits, repeat the experiment to determine possible sources of variability and make changes in the procedure if necessary.

Once you've identified which data are reliable, graph them. It is easier to spot patterns and outliers on a graph than in a table. Furthermore, graphs are used to check assumptions for certain statistical methods. Use bar graphs when one of the variables is categorical (i.e., it has no units of measurement). Use scatterplots and line graphs when both variables are quantitative. Look for an overall trend as well as deviations from the trend. Reduce the data by taking the average (mean) and express variability, where appropriate, in terms of standard deviation or standard error. Never eliminate data without a good reason.

Analyze the data

Once you have a visual summary of the raw data, look for relationships between variables. Do the results match the predictions if the hypothesis is supported? If so, then compare your results to those in the primary references you consulted to develop your hypothesis in the first place. Comparable data from different studies help researchers gain assurance that their conclusions about a particular phenomenon are valid. When analyzing data, however, do not let your predictions affect your objectivity. Do not make your results fit your predictions—instead, modify your hypothesis to fit your results. What is learned from a negated hypothesis can be just as valuable as what is learned from a "successful" experiment.

Keep in mind that there may be no difference between the control and the experimental treatments. If there was no difference, say so, and then try to develop possible explanations for these results.

Try to explain the results

Once you have summarized and analyzed the data, you are ready to develop possible explanations for the results. You previously found information on your topic when you developed your hypothesis. Return to this material to try to explain your results. Do your results agree with those of other researchers? Do you agree with their conclusions? If your results do

not agree, try to determine why not. Were different methods, organisms, or conditions employed? What were some possible sources of error?

You should realize that even some of the most elementary questions in biology have taken hundreds of scientists many years to answer. One approach to the problem may seem promising at first, but as data are collected, problems with the method or other complications may become apparent. Although the scientific method is indeed methodical, it also requires imagination and creativity. Successful scientists are not discouraged when their initial hypotheses are discredited. Instead, they are already revising their hypotheses in light of recent discoveries and planning their next experiment. You will not usually get instant gratification from applying the scientific method to a question, but you are sure to be rewarded with unexpected findings, increased patience, and a greater appreciation for the complexity of biological phenomena.

Revise original hypotheses to take new findings into account

If the data support the hypothesis, then you might design additional experiments to strengthen the hypothesis. If the data do not support the hypothesis, then suggest modifications to the hypothesis or use a different procedure. Ideally, scientists will thoroughly investigate a question until they are satisfied that they can explain the phenomenon of interest.

Share findings with other scientists

The final phase of the scientific method is communicating your results to other scientists, either at scientific meetings or through a publication in a journal. When you submit a paper to refereed journals, it is read critically by other scientists in your field, and your methods, results, and conclusions are scrutinized. If any errors are discovered, they are corrected before your results are communicated to the scientific community at large.

Poster sessions are an excellent way to share preliminary findings with your colleagues. The emphasis in poster presentations is on the methods and the results. The informal atmosphere promotes the exchange of ideas among scientists with common interests. See Chapter 7 on how to prepare a poster.

Oral presentations are different from both journal articles and poster sessions, because the speaker's delivery plays a critical role in the success of the communication. See Chapter 8 for tips on preparing and delivering an effective oral presentation.

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Developing a Literature Search Strategy

The development of library research skills is an essential part of your training as a biology student. A vast body of literature is available on just about every topic. Finding exactly what you need is the hard part.

In biology, sources are divided broadly into primary and secondary references. **Primary references** are the research articles, dissertations, technical reports, or conference papers in which a scientist describes his or her original work. Primary references are written for fellow scientists—in other words, for a specialized audience. The objective of a primary reference is to present the essence of a scientist's work in a way that permits readers to duplicate the work for their own purposes and to refute or build on that work.

Secondary references include encyclopedias, textbooks, articles in popular magazines, and information posted on the websites of professional societies, government agencies, and other scientific organizations. Secondary references are based on primary references, but they address a wider, less-specialized audience. In secondary references, there is less emphasis on the methodology and presentation of data. Instead, the results and their implications are described in general terms for the benefit of non-specialist readers.

You will delve into the biological literature when you write laboratory reports, research papers, and other assignments. Although secondary references provide a good starting point for your work, it is important to be able to locate the primary sources on which the secondary sources are based. Only the primary literature provides you with a description of the methodology and the actual experimental results. With this information, you can draw your own conclusions from the author's data.

Although initially it may be difficult to read primary literature, it will become easier with practice, and the rewards are well worth it. One benefit of *reading* research articles is that you will become a better *writer*. Through reading, you become familiar with the writing style and overall

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TABLE 2.1 Databases and search engines used to find scholarly information in the biological sciences

Database or Search Engine	Description
AGRICOLA	Produced by the US Department of Agriculture's National Agricultural Library, this database contains citations for journal articles, monographs, government publications, patents, and other types of publications in the field of agriculture and related areas.
Biological Abstracts	Considered the most comprehensive database in the area of biology and the life sciences, it provides abstracts and citations to journal literature.
Biological Science (ProQuest)	Indexes scholarly and trade journals, books, conference proceedings, government publications, and other publication types for a wide range of areas in the life sciences.
BioOne	A journal collection of full-text, peer-reviewed articles in biology and the environmental sciences. Most of the journals are published by small scientific societies, other not-for-profits, and open access publishers.
Google Scholar	A Web search engine for scholarly literature across many disciplines, languages, and countries. Includes not only journal articles, but also material from websites of universities, scientific research groups, and professional societies; conference proceedings; court opinions and patents; and preprint archives. (Preprints are manuscripts circulated because they contain current information, but they have not yet been peer reviewed). Articles in the popular press, book reviews, and editorials are not included.

structure of research articles, so that you have a model when you write your own lab reports. Another benefit is that you learn how scientists approach a problem, design experiments to test hypotheses, and interpret their results to arrive at their conclusions. Emulating their writing style may help you improve your critical thinking skills. A further benefit of reading the primary literature is getting to know the scientists who work in a particular subdiscipline. You may discover that you are sufficiently interested in a subdiscipline to pursue graduate work with one or more of the authors of a journal article.

How do you find primary references that are directly relevant to your topic? The fastest and easiest way is to search article databases. Article databases contain a pre-screened collection of scholarly information, not web pages that anyone could have created. Article databases are owned by companies or organizations that employ experts to read scholarly arti-

TABLE 2.1 (continued)

Database or Search Engine	Description
JSTOR	Developed as a digital archive of core scholarly journals, this database searches the full text of core journals in a variety of disciplines including biology and ecology. Coverage begins with the first issue of each journal. However there is a gap, typically from 1 to 5 years, between the most recently published issue and when it appears in JSTOR.
NCBI (National Center for Biotechnology Information)	A division of the US National Library of Medicine. Produces searchable databases on nucleotide and protein sequences, protein structures, complete genomes, taxonomy, and other molecular biology information.
PubMed	Produced by the US National Library of Medicine, PubMed is the public access version of MEDLINE, the premier database for medicine and related fields. It contains abstracts and citations to the worldwide journal literature and books.
ScienceDirect	Provides access to journal articles and books published by Elsevier. Although multidisciplinary, most references are in the areas of science, medicine, and engineering.
Scopus	A database of scientific information resources, including journal articles, books, and conference proceedings. Almost 40% of the records are pre-1996; over 60% of the records are post-1995.
Web of Science	An interdisciplinary database for peer-reviewed articles from core journals in many subject areas. The "Times Cited" and "Cited References" searches allow you to identify more recent and older articles, respectively, which cite a particular author or work.

Source: Kathleen McQuiston, Research Services Librarian, Library and Information Technology, Bucknell University (2016 Oct 23) and respective database or search engine websites.

cles and then enter information about the articles into the database. To find scholarly information on a particular topic, instead of "googling" the entire Web, you will typically search one or more databases.

Most databases (PubMed being the notable exception) are by subscription. Companies that own these databases sell licensing agreements to university libraries and other institutions. If you are affiliated with such a university or institution, then you can use fee-based databases for free. On the other hand, search engines such as Google Scholar, which scan the Web for scientific information, are free and available to the general public. Table 2.1 describes some of the databases and scholarly search engines that you may have access to. Many of these databases have apps that can be installed on your mobile devices.

Most of this chapter describes how to find primary references using databases. If you do not have access to these databases, however, you can still locate references the old-fashioned way. This method involves building a bibliography from sources cited in books, journal articles, and other literature. Books such as *Annual Reviews* are considered secondary references, but the Literature Cited section in review articles often is an excellent source of primary references. Building a bibliography without the use of a database is laborious and time-consuming, but the end result is often the same. An advantage of using this old-fashioned method is that you may find older, seminal papers that may not be indexed in databases. If your assignment requires a thorough search of the literature, you will most likely use a combination of database and manual searches. Don't forget about your human resources—seek assistance from your reference librarian during all stages of your research project.

Databases and Search Engines for Scientific Information

Familiarize yourself with the databases and search engines recommended by your professor or a reference librarian and which are available through your academic library. All of the databases have some overlap in terms

TABLE 2.2 Comparison of features of selected biology databases and search engines

	Biological Abstracts	Google Scholar
Resource type	Database	Search engine
Access (free or fee-based)	Fee-based (usually institutional subscription)	Free
Years covered	1926 to present	Unknown
Sources retrieved	Journal articles	No information provided, but retrieves journal articles, books, preprints, abstracts, technical reports, and other electronic media
Content (number of journals indexed)	Searches more than 5,200 journals in the life sciences	Unknown
Reliability (peer-reviewed materials)	Most journals are peer-reviewed	Unclear whether all journal articles are peer-reviewed

Source: Kathleen McQuiston, Research Services Librarian, Library and Information Technology, Bucknell University (2016 Oct 23) and respective database or search engine websites.

of the journals they index, but there are also unique listings. Results may also vary depending on subject and publication year.

Comparison of databases

One of the great things about electronic databases is that they are continually updated and improved, giving you access to the most current scientific information available on the Internet. But with so many choices and so little time, what's the best strategy for tracking down a few good primary journal articles for your topic? The answer to this question depends on who you ask, how comprehensive your research needs to be, the subject matter, and personal search preferences. Nonetheless, knowing a little about the strengths and weaknesses of some of the major databases and search engines may help guide your strategy (Table 2.2).

Librarians and scholars interested in information technology have published a number of recent papers on this topic (see, for example, Harzing and Alakangas [2016], Hodge and Lacasse [2013], and Moed *et al.* [2016]). While these published comparisons are as transient as the databases they describe, it is nonetheless instructive to look at some of the data.

TABLE 2.2 (continued)

PubMed	Web of Science	Scopus
Database	Database	Database
Free	Fee-based	Fee-based
Generally 1946 to present	1900 to present	1823 to present
Journal articles, literature reviews, clinical trials	Journal articles and conference proceedings	Journal articles, books, patents, and conference proceedings
Biomedical journal citations and abstracts from over 5,000 journals	Searches more than 12,000 journals (all disciplines) and 3.8 million conference proceedings	Searches more than 21,500 journals from more than 5,000 international publishers from all subject areas
Most journals are peer-reviewed	All journals are peer-reviewed	All journals are peer-reviewed

Google Scholar Google Scholar was introduced by Google in 2004. Its strengths are name recognition, a simple query box, and the fact that it's free. In terms of content, Google Scholar is thought to provide greater access to older records and to material not easily located through conventional channels such as publishers' websites. Its web-crawling robots use an algorithm to determine what is "scholarly" based on information provided by authors and publishers on their websites. Some of Google Scholar's weaknesses include the scope of its coverage (it finds too much information), uncertainty about the scholarly value and currency of some of the records, and the sorting of records according to how relevant they are (based in part on how often they were cited). The search results cannot be sorted by date, but a custom date range can be selected.

PubMed PubMed is *the* most recommended database for researchers in medicine who require advanced search functions. Like Google Scholar, PubMed is free and its advanced search feature makes it possible to limit searches by author, publication, and date. PubMed provides a variety of options to retrieve only certain formats (full text, free full text, or abstract), types of article (clinical trial, review, clinical conference, comparative study, government publication, etc.), language, and content (journal group, research topic, humans or animals, gender, and age). Another feature that makes PubMed so powerful is its search algorithm, which is based on concept recognition, not letters or words. Every document indexed for PubMed has been read by experts, who tag the document with controlled vocabulary (Medical Subject Headings or MeSH) that accurately describes the paper's content. "False hits" due to homographs (e.g., swimming pool rather than gene pool) are thus eliminated in PubMed searches. Furthermore, MeSH solves the problem of ambiguity concerning scientific and popular names of organisms, synonyms, and variations in British and American spelling.

Web of Science Web of Science is fee-based, so you may only have access to this database if your university has a subscription. Web of Science covers a larger period of time than either PubMed or Google Scholar. It has depth and scope and is useful for finding information on topics of an interdisciplinary nature. The greatest benefit of this database, however, lies in the fact that once you have found a good journal article, you can expand your bibliography quickly based on common references. With Web of Science, it is possible to search *forward* in time to find more recent papers that have cited the paper of interest. It is also possible to search *backward* to find papers cited by authors of the paper of interest.

Scopus Like Web of Science, Scopus has a tremendous scope in terms of years covered and sources retrieved, and it is fee-based. Scopus, like all of the databases in Table 2.2, has an advanced search feature, provides links to full-text articles, and allows references to be exported to reference management software (see p. 24). In addition, graduate students and career researchers will find the email alerts feature of these databases handy for staying current with the literature. When registering for email alerts, you can enter keywords that are relevant to your research. When a new article containing these keywords appears, the database administrator will send you an email alert.

Database Search Strategies

Finding just the right journal articles on your topic can be a daunting task. This section will help you get started.

Understand your topic

A productive and efficient search begins with a **basic understanding of your topic**. If you don't even know where to start, look up the most specific term you can come up with in the index of your textbook. Open the book to the pages that contain this term. Read the chapter subheadings and the chapter title to learn how this term fits into the bigger picture. Read the relevant pages to find out what subtopics are associated with this term.

Your library's stacks are another good place to find general information. Search the library's catalog to locate a book on your topic. Write down the call number and find this book on the shelf. Browse the titles of other books in the vicinity. Because the Library of Congress cataloging system groups books according to topic, you can often find additional sources shelved nearby.

Encyclopedias and dictionaries may also help you clarify your topic. Check your library's homepage for references that you may have access to, both electronic and printed sources. Websites such as Wikipedia (<http://www.wikipedia.org>), WebMD (<http://www.webmd.com>), and others may be a good place to start, but evaluate Internet sources critically. Whereas journal articles and books have undergone a rigorous review process, information on the Web may not have been checked by any authority other than the owner of the website.

A first step in evaluating a website's reliability is to look at the ending of the URL address (Table 2.3). Is the sponsor of the website a company or organization that is more interested in trying to sell a product or idea than in presenting factual information? To become a savvy website evaluator, check out the tips on your library's homepage or take one of the tutorials listed in the Bibliography.

TABLE 2.3 Identifying sponsors of sites on the World Wide Web

Type of Web Page	Purpose	Ending of URL Address	Examples
Informational	To present (factual) information	.edu, .gov	Dictionaries, directories, information about a topic
Business/marketing	To sell a product	.com	Carolina Biological Supply, Leica
Advocacy	To influence public opinion; to promote the exchange of knowledge and provide resources for its members	.org	Sierra Club, Association for Biology Laboratory Education
News	To present very current information	.com	CNN, USA Today

Source: Alexander and Tate (1996–2005).

Define your research goals

Once you have a basic understanding of your topic, try to define your research goals with statements such as

- I would like to compare or contrast methods.
- I'm looking for a cause-and-effect relationship.
- I want to understand more about a process.
- I am interested in how an organism carries out a particular function (e.g., obtains nutrients, reproduces, moves, responds to changes in its environment).

Subdivide your topic into concepts

Once you have formulated the goals for your topic, start defining smaller concepts. For example, if the methods you wish to compare have to do with measuring the amount of protein in a sample, then one of the concepts is protein quantification. Another concept would include the specific names of protein quantification methods, such as Lowry, biuret, Bradford, BCA, and so on. A third concept might relate to the types of protein samples that were analyzed.

Another way to organize concepts related to your topic is to use PubMed's Medical Subject Headings (MeSH) database, a kind of thesaurus for the life sciences. Words entered in the search box are translated

The screenshot shows the PubMed home page with the following elements:

- Select a database:** A dropdown menu with "PubMed" selected.
- Enter key words:** A search input field.
- PubMed:** A text box containing the text: "PubMed comprises more than 26 million citations for biomedical literature from MEDLINE, research papers, and online books. Citations may include links to full-text content from PubMed Central and publisher web sites."
- PubMed Commons:** A section with a grid of icons and the text: "Featured content in PubMed Commons. Search PubMed Commons for more information." Below this is a "More Resources" section with links for "MeSH Database", "Research Databases", "Clinical Trials", and "Health".
- Using PubMed:** A section with links for "PubMed Site", "PubMed Address", "PubMed URL", "PubMed Tutorial", and "PubMed Database".
- Learn how to use this database:** A section with links for "PubMed Tutorial", "PubMed Database", "PubMed Search", "PubMed Help", "PubMed Database", "PubMed Search", "PubMed Database", "PubMed Search", "PubMed Database".
- Find related, broader, or narrower terms:** A section with a "Find related, broader, or narrower terms" button.

Figure 2.1 PubMed home page provides tutorials and options for searching different databases.

into standardized descriptors, which are then listed in a hierarchy of headings and subheadings.

Let's say, for example, that you would like to find concepts related to the topic "How do *Tetrahymena* move?" Go to the PubMed home page (<https://www.ncbi.nlm.nih.gov/sites/pubmed>) and select MeSH Database under **More Resources** (Figure 2.1). A search for the term *motility* lists *cell movements* as the first result (Figure 2.2); clicking this descriptor opens a page that gives a definition of *cell movement* (not shown in Figure 2.2), entry terms, and the MeSH tree for this concept. The headings below *cell movements* in the tree are narrower concepts and the headings above are broader. Write down the entry terms and headings that are relevant to your topic. While the entry terms are automatically searched in databases that use MeSH, they may be useful keyword alternatives in databases or search engines that do not.

Choose effective keywords

Effective keywords are neither too broad nor too narrow in scope. Keywords that are too broad will retrieve an unmanageable number of articles that, for the most part, are not relevant to your topic. On the other hand, keywords that are too specific may not get any results. For each concept in your topic, therefore, try to come up with moderately specific terms, synonyms, and related descriptors (Figure 2.3). Consider different word endings (photosynthetic versus photosynthesis), abbreviations (HIV for *human immunodeficiency virus*), and alternative spellings (American versus British English). Avoid vague terms like *effect* and *relationship between*.

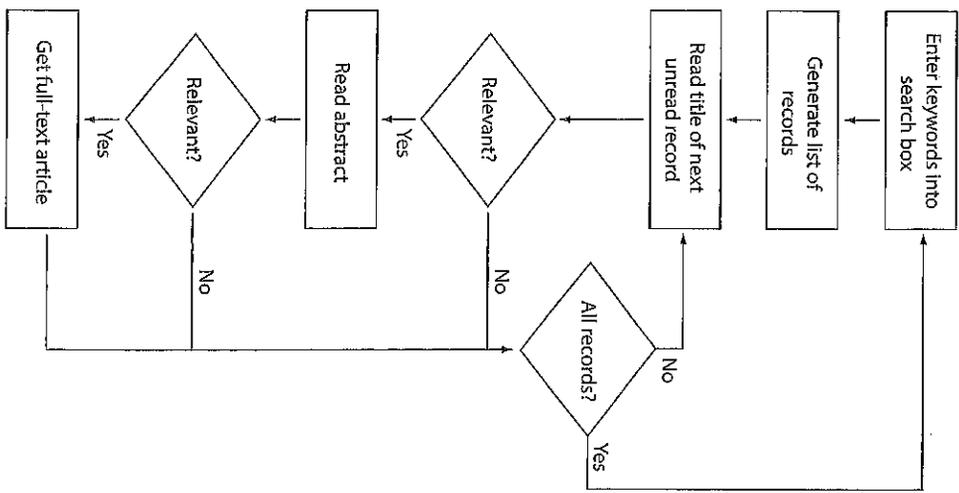


Figure 2.4 Evaluating database or search engine results is an iterative process.

(most recent first), relevance, or another criterion. Each journal article record contains the article title, the authors' names, the name of the journal, the volume and issue numbers, the pages, and the publication date. Based on the title, decide if you want to read the abstract. After having read the abstract, decide whether you want to read the entire paper. This iterative process is summarized in Figure 2.4.

The results pages for Web of Science and PubMed are formatted slightly differently, but both contain the same basic information about the journal articles (Figure 2.5). You will need this information when you

(A) Number of results Search term

WEB OF SCIENCE™

RESULTS: 13

Sort by: Publication Date - Newest to Oldest | Sort by date

1. Respiratory severity of cytomegalovirus infections from adenovirus-associated disease in the neonatal intensive care unit. *Journal of Intensive Care Medicine*. 2015;30(1):1-7.

2. Zoonotic (avian) influenza A virus (H7N9) in Hong Kong. *Emerging Infectious Diseases*. 2015;21(10):1911-1913.

(B) Number of results Search term

PubMed

RESULTS: 13

Sort by: Most Recent | Sort by date

1. Respiratory severity of cytomegalovirus infections from adenovirus-associated disease in the neonatal intensive care unit. *J Intensive Care Med*. 2015;30(1):1-7. doi:10.1177/0885066615578111.

2. Zoonotic (avian) influenza A virus (H7N9) in Hong Kong. *Emerging Infectious Diseases*. 2015;21(10):1911-1913. doi:10.1093/eid/civ210.

(C) More results than Web of Science or PubMed

Google

Journal name Volume: Inclusive pages Authors

1. Respiratory severity of cytomegalovirus infections from adenovirus-associated disease in the neonatal intensive care unit. *J Intensive Care Med*. 2015;30(1):1-7. doi:10.1177/0885066615578111. Zhang Q, Liu B, Zhou L, et al.

2. Zoonotic (avian) influenza A virus (H7N9) in Hong Kong. *Emerging Infectious Diseases*. 2015;21(10):1911-1913. doi:10.1093/eid/civ210. Zhang Q, Liu B, Zhou L, et al.

Figure 2.5 The results page from (A) Web of Science, (B) PubMed, and (C) Google Scholar for the keyword phrase *aphantoxins*.

Sorted according to relevance (based on authors, journal, and number of times cited)

Finds papers on academic social media sites

The screenshot shows a ScienceDirect article page. At the top, there are search and navigation options like 'Google' and 'First report of aphantoxins'. The article title is 'First report of aphantoxins in China—waterblooms of toxicogenic Late Dianchi'. Below the title, there is an abstract: 'The original toxicogenic cyanobacteria (aphantoxin-producing strain) (AP1) has been reported in several reservoirs to produce neurotoxic substances (PSHs) or paralytic toxic effects in the past years. A toxic waterbloom have occurred recently in the reservoir Lake Dianchi (2004) in China. AP1 has been identified as *Scenedesmus dimorphus* (Grunow) Grunow'. The page includes a 'Download to read later' button, 'Save record to reference manager' option, and a 'Print text links' section with options for PDF, HTML, and XML. There are also sections for 'Similar articles' and 'All Times Cited Online'.

Figure 2.6 Detailed record from Web of Science showing the abstract, a link to the full-text article, and links to related articles. The full-text article is stored in ScienceDirect, a repository of academic journals and ebooks managed by Elsevier. The corresponding links from Google Scholar and PubMed lead to the same full-text article. The citation information can also be saved to a reference manager such as EndNote, Mendeley, RefWorks, or Zotero.

cite the article in your lab report or research paper (see the section “Documenting Sources” in Chapter 4). Google Scholar, on the other hand, lists the authors, journal name, year, and publisher followed by an excerpt of the abstract or passage where the keywords are used.

Skim the titles of the first 20 records. If the titles seem to be unrelated to your topic, start a new search with different keywords using the strategies described previously (see the section “Choose effective keywords”). If a title seems promising, click it to open a page that contains the abstract (Figure 2.6). Based on the title and the abstract, decide whether or not you want to read the entire article. In Google Scholar, clicking the title takes you directly to the source text.

Finding related articles

Once you have found a good article, Web of Science makes it easy to find related articles. In the **Times Cited** section, there is a list of more recent papers that cite this article (see Figure 2.6). Clicking on one of these titles opens a new page that displays the abstract of the more recent paper. In the **Cited References** section, you can view the references listed in the article. Browsing the list allows you to find related papers with a slightly different focus. In the **View Related Records** section, papers are listed, which cite references that were also cited in the article. Common references indicate that the authors were pursuing a similar research topic. PubMed also offers a **Similar Articles** option (see Figure 2.6).

Finding review articles is the equivalent of hitting the mother lode. Review articles are secondary references that summarize the findings of all major journal articles on a specific topic since the last review. You can find background information, the state of current knowledge, and a list of the primary journal articles authored by scientists who are working on this topic. If you are unable to find a relevant review article in a database, go directly to the Annual Reviews website (www.annualreviews.org) and search for your topic. If you find a promising review article on this website, you may be able to obtain a copy through your academic library.

Most of the article databases and search engines also have an advanced search option. Advanced search makes it possible for you to limit your search by specifying one or more authors, publication years, journals, and other criteria.

Obtaining full-text articles

If the title and the abstract of an article sound promising, you will want to obtain the full-text article. Web of Science, PubMed, and Google Scholar all have links to full-text articles that you can download as a PDF (see Fig-

ture 2.6). Some publishers also offer an HTML option. PDFs preserve formatting, while HTML files contain hyperlinks that make it easy to access other references. Save the full-text article to your computer or cloud storage space to read later. Copy the URL and write down the download date, because you may need this information when citing the source.

While the abstract is usually free, some publishers charge a fee to access the full-text article. Fortunately, academic libraries and institutions often purchase subscriptions so that faculty, staff, and students can obtain many electronic journal articles for free. If your library does not have a subscription and you are not in a hurry to get the article, you may be able to use interlibrary loan. **Interlibrary loan** is a way for a library to borrow or obtain materials that it does not own from another library or organization.

Managing References (Citations)

Reference management software makes it possible to

- Build your own collection of references from database searches.
- Insert citations into a paper.
- Format both the in-text reference and the end reference according to the style specified by your instructor. You can select from hundreds of styles, including the familiar CSE, APA, MLA, and Chicago styles. If you are submitting your paper to a journal, RefWorks even offers styles for specific journals.

Some of these products are free to everyone (e.g., Mendeley and Zotero) and others are free as long as you are affiliated with a subscribing institution (e.g., RefWorks and EndNote).

Many scientists and other scholars rely heavily on reference management software to organize all of their references. Students will appreciate the convenience and ease of use of these programs as well. The following instructions for RefWorks are intended simply to make you aware of the possibilities. If you like what you see, ask your librarian if you can access something similar at your school.

ProQuest RefWorks

Create an account Go to the RefWorks login page found at <https://refworks.proquest.com>. Enter your institution's credentials and create an account. You will receive an email confirmation to complete the process. To learn the basics of RefWorks in 20 minutes, watch the helpful YouTube tutorials available at https://www.youtube.com/channel/UCzmtJ_AGcY59VoNiv-0SvccGg.

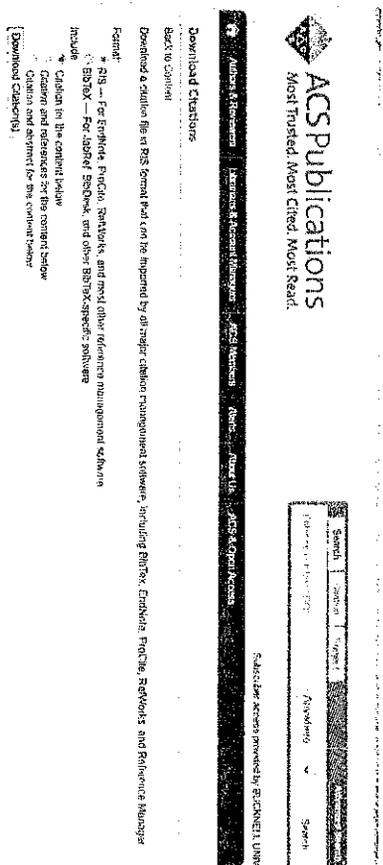


Figure 2.7 The Download Citations dialog box is used to specify the format (use RIS for RefWorks) and whether the abstract or any references are to be included with the citation.

Download citation into RefWorks

1. After you have found a reference that seems useful, click the **Cite or Export or Download to citation manager** link in the database or on the publisher's website.
2. In the Download Citations dialog box, click the desired content: **Citation only**, **Citation and references**, or **Citation and abstract** (Figure 2.7). Click **Download Citation(s)**. The citation file will be downloaded to your computer in RIS format.
3. In RefWorks, click + (**Add a Reference**) | **Import References** (Figure 2.8). Under **Import from a file**, click the “select a file from your computer” hyperlink, navigate to the .ris file, and click **Open**. It doesn't seem to matter that Abbott Labs is the default, even though the file was downloaded from a different database.
4. The dialog box will notify you that 1 reference was imported. Click **Last Imported** to see the details of the reference.
5. References are easier to find when they are assigned to folders. To create a new folder, click **My Folders** | **Add a folder** (see Figure 2.8). Then drag the imported reference into the new folder or into an existing one.

Download Write-N-Cite or RefWorks Citation Manager Before you can insert the references you saved in RefWorks into a paper, you have to download an add-in to your computer.

- Citation-Sequence
- Name-Year
- Citation-Name

The Citation-Name system is a hybrid of the other two and will be discussed briefly in Chapters 3 and 4.

CITATION-SEQUENCE (C-S)

In the Citation-Sequence system, in-text references are numbered sequentially and the corresponding full reference is given in a numbered list at the end of the paper.

1. Begin typing your paper in Word. Save the document after you come to a sentence in which you want to cite a reference.
2. Click the down arrow next to **RefWorks | Citation & Bibliography | style**. The Council of Science Editors styles are not among the top six styles listed. To add CSE styles to the list, open RefWorks in your browser and click the "**Create Bibliography**)" button and then **Create Bibliography**. In the second field from the left on the menu bar, click the down arrow and type "cse" into the search box. Select the **Council of Science Editors – CSE 8th, Citation-Sequence** style.

3. Back in your Word document, click **RefWorks | Extras | Sync My Database** to download the new style to your computer. The six most recently used styles are displayed.

4. Position the cursor *one space after the word* or *after the period* where you want to cite a reference. Click **RefWorks | Citation & Bibliography | Insert Citation**. In the **Insert/Edit Citation** dialog box, navigate to the relevant folder and click the reference that is to be cited (see Figure 2.9). A superscripted number will appear in the Word document.

5. Repeat this process for each reference to be cited.

6. Save the document just before you are ready to generate the end reference list (bibliography). This step is important, because Write-N-Cite will not properly format the in-text reference and the end references list if the document has not been saved.

7. Position the cursor at the end of the document. Click **RefWorks | Citation & Bibliography | Bibliography Options | Insert Bibliography** (Figure 2.10).

8. In your Word document, in-text references are listed sequentially and the information in the end references is in the correct order. Minor editing may be required, but think of the time you'll save by not having to type reference lists!

To insert references reported worldwide, including in New Hampshire, Greece², and Germany.³

References

1. Sasser, JI, Kwang M, Loyall TL, Watson WH. Studies on adriaphotoxin from *adriaphomonas flocculosa* in new Hampshire. In: Wayne W, Carmichael, editor. The water environment: Algal toxins and health. Boston, MA: Springer US, 1981. ID: Sasser1981.
2. Grelis S, Zouras N. Cyanotoxin occurrence and potentially toxin producing cyanobacteria in freshwaters of Greece: A multi-disciplinary approach. *Toxicon* 2014;72:1-9.
3. Dabbschek PK, Selmecky G, Vasek G, Radtschik J, Arr W, Japollizal K, Casper P, Kientz L. Presence of potential toxin-producing cyanobacteria in an oligo-mesotrophic lake in Baltic lake district, Germany: An ecological, genetic and toxicological survey. *Toxins* 2014;6(10):2912-31.

Figure 2.10 Final appearance of a sample lab report formatted using the Citation-Sequence system. After clicking **Bibliography Options | Insert Bibliography**, Write-N-Cite generates the end reference list based on the style selected.

NAME-YEAR (N-Y)

In the Name-Year system, the in-text reference is given in the form of author and year. The number of authors determines the format of the citation:

- 1 author: Author's last name followed by year of publication
- 2 authors: First author's last name and second author's last name followed by year of publication
- 3 or more authors: First author's last name followed by the words and others (or *et al.*) and year of publication

The corresponding full references are listed alphabetically at the end of the paper.

1. Begin typing your paper in Word. Save the document after you come to a sentence in which you want to cite a reference.

2. Click the down arrow next to **RefWorks | Citation & Bibliography | style**. The Council of Science Editors styles are not among the top six styles listed. To add CSE styles to the list, open RefWorks in your browser and click the "**Create Bibliography**)" button and then **Create Bibliography**. In the second field from the left on the menu bar, click the down arrow and type "cse" into the search box. Select the **Council of Science Editors – CSE 8th, Name-Year Sequence** style.

3. Back in your Word document, click **References** | **Extras** | **Sync My Database** to download the new style to your computer. The six most recently used styles are displayed.
4. Position the cursor *one space after the word or ahead of the period* where you want to cite a reference. Click **References** | **Citation & Bibliography** | **Insert Citation**. In the **Insert/Edit Citation** dialog box, navigate to the relevant folder and click the reference that is to be cited (see Figure 2.9).
5. Repeat this process for each reference to be cited.
6. Save the document just before you are ready to generate the end reference list. This step is important, because Write-N-Cite will not properly format the in-text reference and the end references list if the document has not been saved.
7. Position the cursor at the end of the document. Click **References** | **Citation & Bibliography** | **Bibliography Options** | **Insert Bibliography**.
8. In your Word document, in-text references are listed in alphabetical order, and the information in the end references is in the correct order (Figure 2.11). Minor editing may be required, but think of the time you'll save by not having to type reference lists!

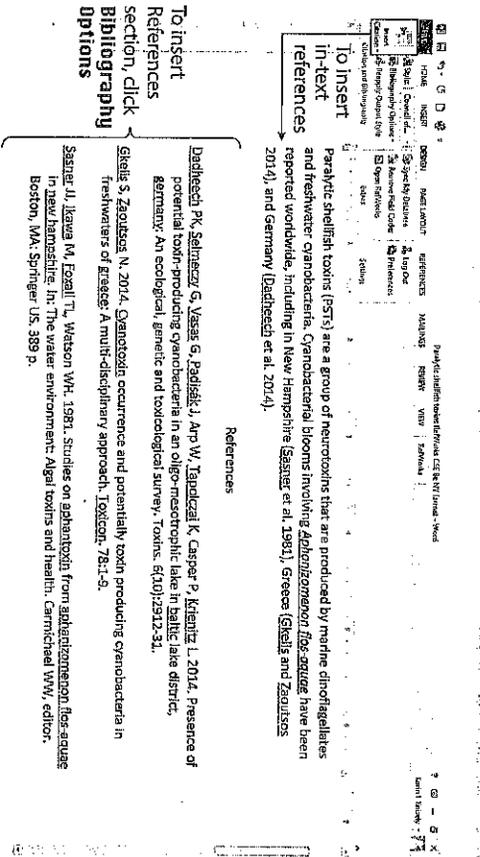


Figure 2.11 Final appearance of a sample lab report formatted using the Name-Year system. After clicking **Bibliography Options** | **Insert Bibliography**, Write-N-Cite generates the end reference list based on the style selected.

Go to the **COMPANION WEBSITE** • sites.sinauer.com/knisely5e for samples, template files, and tutorial videos

Reading and Writing Scientific Papers

Reading and writing are two sides of the same coin. We read to acquire knowledge and write to disseminate it. Acquiring knowledge in biology is not just about memorizing facts and practicing lab techniques. Knowledge acquisition is a lifelong process that involves mastering the basics, applying basic information to new situations and problems, and reviewing and reciting the information at regular intervals until it becomes second nature. Disseminating knowledge through written and oral communications requires a certain mastery of the subject matter. Although writing may help you identify gaps in your knowledge, lab reports and other forms of scientific communication are best written *after* you have struggled to understand the material. Your understanding must then be translated into words that convey knowledge clearly and concisely to your readers. Writing well is hard work, but in the long run, good communication skills will open doors to an interesting, challenging, and financially rewarding career in biology.

Types of Scientific Communications

Scientific writing takes many forms. As an undergraduate biology major, you will be asked to write laboratory reports, answer essay questions on exams, paraphrase information from journal articles, and do literature surveys on topics of interest. Third- and fourth-year college students may write research proposals and honors theses and present their work at poster sessions and other venues. Graduate students typically write master's theses and doctoral dissertations and present talks about their research at national and international conferences. Professors write lectures, letters of recommendation for students, grant proposals, reviews of articles submitted for publication to scientific journals by their colleagues, and evaluations of grant proposals. In business and industry, scientific writing may take the form of progress reports, product descriptions, oper-

3. Back in your Word document, click **RefWorks | Extras | Sync My Database** to download the new style to your computer. The six most recently used styles are displayed.
4. Position the cursor *one space after the word or ahead of the period* where you want to cite a reference. Click **RefWorks | Citation & Bibliography | Insert Citation**. In the **Insert/Edit Citation** dialog box, navigate to the relevant folder and click the reference that is to be cited (see Figure 2.9).
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8. In your Word document, in-text references are listed in alphabetical order, and the information in the end references is in the correct order (Figure 2.11). Minor editing may be required, but think of the time you'll save by not having to type reference lists!

The screenshot shows a Microsoft Word document with a list of references. The references are as follows:

Dehnebeck PK, Salinas G, Padisák J, App W, Tapočaj K, Casper P, Kriantiz L 2014. Presence of potential toxin-producing cyanobacteria in an oligo-mesotrophic lake in Baltic lake district. An ecological, genetic and toxicological survey. *Toxins*. 6(10):2322-31.

Gleis S, Zedler S, N. 2014. Cyanotoxin occurrence and potentially toxin producing cyanobacteria in freshwaterers of Greece: A multi-disciplinary approach. *Toxicon*. 78:1-9.

Saenger JI, Likens G, Foxall TL, Watson WH. 1981. Studies on alphanitroxin from *aphanizomenon flos-aquae* in New Hampshire. In: The water environment: Algal toxins and health. Garnierthal WW, editor. Boston, MA: Springer US. 389 p.

At the bottom of the list, there is a section titled "References" which is currently empty.

Figure 2.11 Final appearance of a sample lab report formatted using the Name-Year system. After clicking **Bibliography Options | Insert Bibliography**, Write-N-Cite generates the end reference list based on the style selected.

Go to the **COMPANION WEBSITE** • sites.sinauer.com/kniseley5e for samples, template files, and tutorial videos

Reading and Writing Scientific Papers

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ating manuals, and sales and marketing material. Medical writers research and prepare various kinds of documents and educational materials for healthcare professionals, pharmaceutical companies, and regulatory agencies. Journalists write about science for a broad, non-specialist audience.

Hallmarks of Scientific Writing

What distinguishes scientific writing from other kinds of writing? One difference is the motive. Scientific writing aims to inform rather than to entertain the reader. The reader is typically a fellow scientist who intends to use this information to

- Stay current in his or her field.
- Build on what is already known.
- Improve a method or adapt a method to a different research question.
- Make a process easier or more efficient.
- Improve a product.

A second difference is the style. Brevity, a standard format, and proper use of grammar and punctuation are the hallmarks of well-written scientific papers. The authors have something important to communicate, and they want to make sure that others understand the significance of their work. Flowery language and “stream of consciousness” prose are not appropriate in scientific writing because they can obscure the writer’s intended meaning.

A third difference between scientific and other types of writing is the tone. Scientific writing is factual and objective. The writer presents information without emotion and without editorializing.

Scientific Paper Format

Scientific papers, or research papers, are descriptions of how the scientific method was used to study a problem. They follow a standard format that allows the reader, first, to determine initial interest in the paper, second, to read a summary of the paper to learn more, and, finally, to read specific sections of the paper itself for particular details. This format is very convenient, because it allows busy people to scan volumes of information in a relatively short time, and then spend more time reading only those papers that truly provide the information they need.

Almost all scientific papers are organized as follows:

- Title
- List of authors
- Abstract

- Introduction
- Materials and Methods
- Results
- Discussion
- Acknowledgments
- References

This standard structure is sometimes called the IMRD format. IMR is an abbreviation of the core sections of a scientific paper.

The **Title** is a **short, informative description of the essence of paper**. It should contain the fewest number of words that accurately convey the content. Readers use the title to determine their initial interest in the paper.

Only the names of **people who played an active role** in designing the experiment, carrying it out, and analyzing the data appear in the **List of Authors**.

The **Abstract** is a **summary of the entire paper** in 250 words or less. It contains (1) an introduction (scope and purpose), (2) a short description of the methods, (3) results, and (4) conclusions. There are no literature citations or references to figures in the abstract. If the title sounds promising, readers will use the abstract to determine if they are interested in reading the entire paper.

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 or historical perspective on the topic.** Primary journal articles and review articles, rather than textbooks and newspaper articles, are cited to provide the reader with direct access to the original work. Inconsistencies, unanswered questions or new questions that resulted from previous work set the stage for the present study.
2. **Statement of objectives of the work.** What were the goals of the present study?

The **Materials and Methods** section describes, in full sentences well-developed paragraphs, **how the experiment was done**. The author provides sufficient detail to allow another scientist to repeat the experiment. Volume, mass, concentration, growth conditions, temperature, type of microscopy, statistical analyses, and sampling techniques are all included. The **Results** section reports the data that were collected. The **Discussion** is a critical analysis of the results. The **Conclusions** are the author’s interpretation of the results. The **Acknowledgments** section is optional. The **References** are a list of all the literature cited in the paper. The **References** are a list of all the literature cited in the paper. The **References** are a list of all the literature cited in the paper. The **References** are a list of all the literature cited in the paper.

to the audience) are not explained. In some instances, it is appropriate to use references to describe methods.

The **Results** section is where the findings of the experiment are summarized, without giving any explanations as to their significance (the “whys” are reserved for the Discussion section). A good Results section has two components:

- A *text*, which forms the body of this section
- Some form of *visual* that helps the reader comprehend the data and get the message faster than from reading a lengthy description

In the **Discussion** section, the results are interpreted and possible explanations are given. The author may:

- Summarize the results in a way that supports the conclusions.
- Describe how the results relate to existing knowledge (literature sources).
- Describe inconsistencies in the data; this is preferable to concealing an anomalous result.
- Discuss possible sources of error.
- Describe future extensions of the current work.

In the **Acknowledgments** section of published research articles, the authors recognize technicians, colleagues, and others who have contributed to the research or production of the paper. In addition, the authors acknowledge the organization(s) that provided funding for the work as well as individuals who provided non-commercially available products or organisms.

References list the **outside sources** the authors consulted in preparing the paper. No one has time to return to a state of zero knowledge and rediscover known mechanisms and relationships. That is why scientists rely so heavily on information published by their colleagues. References are typically cited in the Introduction and Discussion sections of a scientific paper, and the procedures given in the Materials and Methods section are often modifications of those in previous work.

Styles for Documenting References

The Council of Science Editors (CSE Manual 2014) recommends the following three systems for documenting references:

Citation-Sequence System. In the *text*, the source of the cited information is provided in an abbreviated form as a superscripted endnote or a number in square brackets or parentheses. On the *references pages* that follow the Discussion section, the sources are listed in **numerical order** and include the full reference.

Name-Year System. In the *text*, the source is given in the form of author(s) and year. On the *references pages* that follow the Discussion section, the references are listed in **alphabetical order** according to the first author’s last name.

Citation-Name System. This system is a hybrid of the Citation-Sequence and Name-Year systems. In the *text*, the source of the cited information is provided in an abbreviated form as a superscripted endnote or a number in square brackets or parentheses. On the *references pages* that follow the Discussion section, the references are listed in **alphabetical order** according to the first author’s last name. The references are then numbered sequentially.

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 reference without having to check the reference list. This system is more commonly used and generally is preferred. With the Citation-Sequence and Citation-Name systems, for each reference the reader in turn to the reference list at the end of the paper to gain the same information. The Name-Year and Citation-Sequence systems are described in detail on pp. 90–94.

Strategies for Reading Journal Articles

The *way* you read a journal article depends on *why* you are reading. The strategy described below is a modification of the SQ3R method recommended by learning support staff to improve reading comprehension (see, for example, resources posted by The Teaching and Learning Center at Bucknell University 2016; Counselling Services at the University of Victoria 2016; and links within these websites to other websites). The method itself takes longer to complete than simply sitting down and passively reading the article. However, the investment in time is rewarded deeper understanding and the ability to recall the information for a long time afterwards.

Prereading. Also called *previewing* or *surveying*. This method involves skimming a text to get an overview or to find specific information. Prereading is designed for speed, not comprehension. Thus you would pre-read a journal article to decide if you are sufficiently interested in the content to read the article carefully later. Start by skimming the title, the abstract, the key words (if present), and the first few sentences of the introduction. If the paper seems promising, look for specific information by section. The standard IMRD structure facilitates this process.

Reading for comprehension. Let's assume that you *want* to read this journal article. First pre-read it to get an idea of the topic, as described above. Then take some time to reflect on what you already know about this topic. If you find that this article is way over your head, you will need to acquire background information. With appropriate background information, you can then engage actively with the content by formulating questions and seeking answers. Write the answers in your own words and then practice saying them out loud from memory. Discuss your newly acquired knowledge with your study group or instructor to improve your understanding. Then share your knowledge. Each of these steps is described below.

Acquire background information on the topic

Papers in scientific journals are written by experts in the field. Because you are not yet an expert, you will probably find it difficult to read and understand journal articles. Even experts may read journal articles several times before they understand the methodology and the implications of the findings.

For convenience, you may start looking for background information on a topic by entering key words in Google, Wikipedia, or even YouTube. However, these websites should not be considered authoritative sources for academic work. A better choice may be your textbook, written by scientists and reviewed by other scientists before publication. Because textbook authors generally write for a student audience, not a group of experts, your textbook is likely to be easier to read than the primary literature. See "Strategies for Reading your Textbook" on pp. 39–42 for ways to read biology textbooks efficiently.

Formulate questions

Active reading means reading with a purpose. Scientists read journal articles specifically to acquire the most up-to-date knowledge about a topic directly from the researchers who did the work. In other words, like those scientists, you are reading a journal article to find answers to specific questions. So before you begin reading, make a list of questions. The following questions, divided according to section, will help you read journal articles with focus.

For the introduction The structure of the introduction is broad to specific. The first few sentences are aimed at attracting reader interest, and the topic is introduced in general terms. Subsequent sentences narrow down the topic, setting the stage for the specific goals of the study, which are usually stated in the last few sentences.

- What is the general topic of this paper?
- What aspect of this topic is being studied?
- What was already known about the specific topic?
- What was unknown or what questions were the authors trying to answer?
- What was the authors' approach?
- Did the authors propose any hypotheses?
- What specialist terminology (jargon) do I need to define?

For the materials and methods

- What was the *general* approach?
- What *specific* methods were used?
- Am I familiar with these methods? (If not, acquire background information from secondary sources.)

For the results Look at each figure and read the figure caption to determine what kind of results were collected. Results can be descriptive or numerical.

Photographs, gel images, phylogenetic trees, maps, and flow charts typically show descriptive data. Tables may also contain descriptive data. Possible questions to ask about these kinds of visual aids include:

- What is the subject of the figure (or table)?
- Does the figure show a sequence of events? If so, what is that sequence?
- Are there any labeled organelles, structures, or marks? Why are they important?
- Does the picture show a relationship between form and function? If so, what is the relationship?
- Are there any noteworthy patterns? If so, what is the pattern?

Graphs always show quantitative (numerical) data. Look at each graph and identify the variables. By convention, the independent variable (the one the investigator manipulated) 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 bar graphs, one of the variables is typically categorical rather than quantitative.

- What was the relationship between the independent and dependent variables?

- If a hypothesis was tested, was there a difference between the controls and the treatment groups? If so, how were they different?

For the discussion The structure of the Discussion section is a triangle, narrow at the top and wide at the base. Information flows from specific to broad (just the opposite of the introduction). The first few paragraphs present the results along with the authors' interpretation. In the next part of the discussion, the results are compared with those in other research papers. The discussion often wraps up with the authors' main conclusions or how this work contributes to the body of knowledge on this topic.

- What were the main results?
- What do the results mean?
- What was the authors' most important conclusion?

Read selectively

With your list of questions in hand, you are now able to read the article with a specific goal: to find the answers to your questions. Tech-savvy readers who have downloaded PDF versions of journal articles may open them in Adobe Reader and enter key words from their questions to search the document for answers quickly and systematically. Whether you use the document search feature or not, write the answers in your own words. If the answers raise new questions, write them down, too, so that you can find those answers later.

Recite

Recite means to say out loud from memory. Whereas reading uses your eyes and writing uses your hands, reciting forces you to speak and listen. When you use multiple senses in a learning environment, you make more connections, which lead to deeper understanding and better recall. Go to a room where you won't be embarrassed to talk to yourself. Read each of your answers out loud. Listen to yourself speak. Are these words *you* would use or are they someone else's? Does one sentence follow logically from the previous one? Keep practicing until you can answer the questions in your own words without looking at your answer sheet. If you are having trouble with this step, have a conversation with your study group or instructor to clarify your understanding.

Review

Take a step back and review what you've learned. Were you able to find answers to all of your questions, both the original ones and the new ones? Are you unsure of any of your answers? The question and answer

approach to reading makes it easier to articulate what it is that you don't understand. Get help and then review again. The review process gives you multiple opportunities to reflect on what you've learned, identify gaps in your understanding, and think about topics at a deeper level.

Share your knowledge

It's no secret that sharing what you've learned with others reinforces your own knowledge. That said, you probably had a specific reason for reading a journal article, and that reason determines *how* you share your knowledge. For example, you may be asked to analyze the results on an exam, or present the paper to your journal club or research group, or cite the paper in a lab report, research proposal, poster, or thesis to demonstrate that you are familiar with the most current knowledge on this topic. Other examples of how scientific knowledge is shared are given on p. 31–32.

Strategies for Reading Your Textbook

If a textbook is required for your course, you can be sure that your instructor expects you to read it. Keep up with your readings. Before each class, pre-read the text as described in "Survey the content" below. Go to class, take notes, and then actually *read* the assigned text, focusing on the topics emphasized in class. Reading for comprehension requires your full concentration. Turn off your cell phone and eliminate all other distractions for 30–40 minutes. Then take a short break. Repeat the process. You will find that you can accomplish much more in less time when you focus on one thing at a time.

The following strategy for reading your textbook is recommended by many university teaching and learning support centers (see, for example, resources posted by The Teaching and Learning Center at Bucknell University 2016; Counselling Services at the University of Victoria 2016; and links within these websites to other websites). The steps follow the **SQ3R method** (survey, question, read, recite, review), which was developed to help students learn and remember what they read. The process takes more time in the beginning, but it saves you time studying in the long run. The following steps work best with a chapter no longer than 25–30 pages.

Survey the content

This first step in the SQ3R method should not take a lot of time and should be done before class. Look over the assigned pages to get an overview of the content. Figure out the main topics by skimming the chapter title, the introduction, the end-of-chapter summary, and the check-your-understanding questions and problems. Then assess the level of detail by skim-

ning the headings and subheadings as well as the pictures. Finally, scan the text for boldfaced terms, which are often vocabulary words that you are expected to know. Preading the chapter before class allows you to spend less time writing and more time listening, because you already know what information is covered in your textbook.

Go to class and take notes

Some instructors provide PowerPoint slide decks for their lectures, or your textbook may come with a printed lecture notebook or a DVD with the figures. Bring these printouts to class to use when taking notes. Write down anything the instructor writes on the board. Write down anything associated with the words “This is important.” Develop your own shorthand system for taking notes. If you missed something, insert a big question mark so that you can fill in the missing information later. Your notes form a framework for organizing information about the topic, and they help you identify the key concepts that were emphasized in lecture. With your notes as a reference, reading becomes an exercise in elaborating on details and making connections.

Formulate questions

Before you start reading, ask yourself, “What do I already know about this topic?” Make a list of key concepts that you remember. Keep this list handy so that you can correct any misconceptions after you finish reading.

Now review your notes and formulate questions about the topics. Reading engages the eyes, but thinking about the topics and writing down questions provides your brain with additional sensory input. The more senses you engage in learning, the better your memory recall. Here are some possible questions that will help you engage actively with the material.

- Why is [this topic] important?
- How is [topic 1] related to [topic 2]?
- How is [topic 1] different from [topic 2]?
- What experimental evidence led to our current understanding of this topic?
- Why was this approach to the problem taken? Would another also have worked?

Read selectively

Find the sections in your assigned reading that cover the topics emphasized in class. Fill in the gaps in your notes. Find the answers to your ques-

tions. As you do so, note any new questions that arise. Note any points of confusion. Define every word so that you become comfortable with the vocabulary. When symbols and formulas are involved, state in words what the terms mean. Interpret any graphs or other experimental data. Make diagrams and concept maps to help you see how topics are related.

Recite

After you’re satisfied that you’ve found answers to your questions, say them out loud using your own words. The combination of speaking and listening engages two additional senses, enhancing your ability to process and remember the information. The acts of speaking and listening may also help you catch errors of logic and missed connections, especially when done in the presence of your study group or instructor. Repeat and refine your answers until you can recite them with confidence.

Review

Set aside a block of time at regular intervals to review your class notes and your reading notes. If you have trouble remembering all of the information, schedule your personal review sessions at more frequent intervals. Definitely try to answer any “Test Your Understanding” questions that come with your textbook. Work the problems without looking at the answers. When you get a wrong answer, try to pinpoint exactly where you went wrong. Articulating what you don’t understand will help your instructor give you the kinds of cues that will allow you to figure out the answer for yourself.

Concept (mind) mapping

A concept map (also called a *mind map*) is a type of flow chart that links smaller concepts to a main concept. Mind maps are a way for readers to organize knowledge about a topic visually. Mind mapping is based on the premise that new knowledge must be integrated with existing knowledge before further learning is possible. Without this integration, new knowledge is quickly forgotten and misconceptions in existing knowledge will continue to persist (Novak and Cañas 2008). When used with an active reading strategy such as the SQ3R method described above, mind mapping is a powerful way to think about concepts more deeply and retain the information longer (University of Victoria Counselling Services, Reading and Concept Mapping Learning Module, 2016).

The strategy described here works best with a chapter or section of text no longer than 25–30 pages (Palmer-Stone 2001).

1. Take no more than 25 minutes to:
 - Read the chapter title, introduction, and summary (at the end of the chapter, if present).
 - Read the headings and subheadings.
 - Read the chapter title, introduction, summary, headings, and subheadings again.
 - Skim the topic sentence of each paragraph (usually the first or second sentence).
 - Skim italicized or boldfaced words.
2. Close your textbook. Take a full 30 minutes to:
 - Write down everything you can remember about what you read in the chapter (make a mind map). Each time you come to a dead end, use memory techniques such as associating ideas from your reading to lecture notes or other life experiences; visualizing pages, pictures, or graphs; staring out the window to daydream; and letting your mind go blank.
 - Figure out how all this material is related. Organize it according to what makes sense in your mind, not necessarily according to how it is organized in the textbook. Write down questions and possible contradictions to check on later.
3. Open your textbook. Fill in the blanks in your mind map with a different colored pencil.
4. Read the chapter again, this time normally. Make another mind map.
5. Review the material at regular intervals. If you can't construct your mind map in sufficient detail (i.e., you have forgotten much of what you read), then review more frequently.

How to Succeed in College

Success in college starts with having the right attitude. You may not be interested in every topic in every course, but it is important to look at the big picture. You *choose* to go to college because you expect that the knowledge and skills learned in college will help you achieve your short-term and long-term goals. *Meaningful* learning, however, requires a conscious decision to *want* to learn.

Assuming you are motivated to learn, how can you make the most of your study time? What counts is not how much time, but the quality of the time you spend studying. Take advantage of your school's resources to develop good time management and study skills in your first semes-

ter. Some strategies include putting due dates for all assignments in your calendar; planning ahead, especially when you have multiple exams or papers in the same week; scheduling study time in blocks of 30-40 minutes with breaks in between; reviewing class notes as soon as possible after class; reviewing material in short, frequent sessions rather than in one long, drawn-out sitting the day before an exam. Figure out where, when, and how you learn most effectively.

Finally, take advantage of all of your resources. Most biology textbooks come with instructions for using the book. Take the time to read those instructions, because they tell you how to use the various components—including online resources—most effectively. Join a study group (see below), attend all classes and recitations, and go to your instructor's office hours to seek help sooner rather than later. Keep in mind that learning takes time, effort, and repetition, and your willingness to learn makes all the difference in a successful academic experience.

Study Groups

If you have read the material several times, taken notes, and listened attentively in lecture, but still have questions, talk about the material with your classmates. Small study groups are one reason why students who choose to major in the sciences persist in the sciences, rather than switching to a non-science major (Light 2001).

What are some benefits of participating in small study groups? One benefit is the comfort level. You may be more likely to talk about problems when you are among your peers; after all, they are not the ones who assign your grade. Secondly, when a group is composed of peers with a similar knowledge base, group members speak the same language. Your instructor speaks a different language, because he or she has already struggled to master the material. When you communicate with your classmates, you verbalize your ideas at a level that is appropriate for your audience of peers. Finally, collaborative learning reflects the way scientists exchange information and share findings in the real world. A spirit of camaraderie develops when people work together toward a common goal. The prospect of learning difficult subject matter is no longer so daunting when you have support from a small group of like-minded individuals. The hard work may even be fun when there is good group chemistry.

Group study is not a substitute for studying alone, however. You must hold yourself accountable for reading the material, taking notes, and figuring out what you do not understand before you meet with your group. If you have not struggled to understand the material yourself, you are not in a position to help a classmate.

Plagiarism

Plagiarism is using someone else's ideas or work without acknowledging the source. Plagiarism is ethically wrong and demonstrates a lack of respect for members of your academic community (faculty and fellow students) and the scientific community in general. Many instructors are now using plagiarism checking services such as Turnitin® and SafeAssign™ by Blackboard to discourage *intentional* plagiarism, such as “borrowing” portions of another student's work, recycling lab reports from previous years, and buying papers on the Internet. Plagiarists who are caught can expect to receive at a minimum a failing grade on the assignment and close scrutiny in subsequent work. Plagiarism may also be cause for expulsion from school.

Many cases of plagiarism are *unintentional*, however, and stem from issues such as:

- Failure to understand what kind of information must be acknowledged
- Failure to reference the original material properly
- Failure to understand the subject matter clearly

Information that does not have to be acknowledged

General information that is obtained from sources such as news media, textbooks, and encyclopedias does not have to be acknowledged.

EXAMPLE: Most of the ATP in eukaryotic cells is produced in the mitochondria.

Information that is common knowledge for your audience does not have to be acknowledged. In an introductory course in cell and molecular biology, for example, students would be expected to know that ATP synthase is the enzyme that produces ATP through oxidative phosphorylation.

EXAMPLE: ATP is synthesized when protons flow down their electrochemical gradient through a channel in ATP synthase.

Information that has to be acknowledged

Information that falls into any of the following categories must be acknowledged:

- Information that is not widely known
- Controversial statements, opinions, or other people's conclusions
- Pictures or illustrations that you use but did not produce
- Statistics or formulas used in someone else's work
- Direct quotations

Paraphrasing the source text

Direct quotations are used in the humanities, but usually not in scientific papers. This idiosyncrasy of technical writing requires you to paraphrase the information in the source document. **Paraphrasing**—using your own words to express someone else's ideas—requires considerable thought and effort on your part. Not only do you have to have sufficient knowledge about the subject, you have to feel comfortable using the vocabulary. Read your textbook and other secondary sources, discuss the topic in your study group, or ask your instructor for clarification. A lot of groundwork has to be done before you can even begin to read a journal article, let alone paraphrase information it contains.

After you have sufficient background information on the topic, you are ready to tackle the content. Accept the fact that comprehension is an ongoing process in which you will read the source text, process the information you've read, read the text again, and process some more. When you are comfortable with the content, take notes on the important points, following the collective advice of Hofmann (2014), Lannon and Gurak (2011), McMillan (2012), Pechenik (2016), and other authorities on scientific writing:

- Don't take notes until you have read the source text at least twice.
- Don't look at the source text when you are taking notes.
- Use your own words and write in your own style.
- Retain key words.
- Don't use full sentences.
- Distinguish your own ideas and questions from those of the source text (e.g., “Me: Applies only to prokaryotes?”).
- Use quotation marks to indicate exact or similar wording. Keep in mind that you will have to put the information into your own words if you use the information in your paper.
- Don't cite out of context. Preserve the author's original meaning.
- Give yourself permission to not understand everything. If it's important, get help.
- Fully document the source for later listing in the end references.

Faulty note-taking practices, particularly those that involve copying large portions of the original text, are likely to result in unintentional plagiarism. Beware of the pitfalls illustrated in Table 3.1. To avoid plagiarizing and avoiding plagiarism, take Frick's (2016) excellent online plagiarism tutorial. Read your institution's policies on academic responsibility, consult with professionals at your school's writing center, and ask your instructor for clarification when in doubt.

TABLE 3.1 Examples of plagiarism

Original Text	Reason
F_1 extends from the membrane, with the α and β subunits alternating around a central subunit γ . ATP synthesis occurs alternately in different β subunits; the cooperative tight binding of $ADP + P_i$ at one catalytic site being coupled to ATP release at a second. The differences in binding affinities appear to be caused by rotation of the γ subunit in the center of the $\alpha_3\beta_3$ hexamer.	
Plagiarized Text	Reason
According to Fillingame (1997), F_1 extends from the membrane, with the α and β subunits alternating around a central subunit γ . ATP synthesis occurs alternately in different β subunits, the cooperative tight binding of $ADP + P_i$ at one catalytic site being coupled to ATP release at a second. The differences in binding affinities appear to be caused by rotation of the γ subunit in the center of the $\alpha_3\beta_3$ hexamer.	The author's actual words were used without quotation marks or indenting the citation. Because direct quotations are not used in scientific papers, it is imperative that you paraphrase. Using the original text is plagiarism even when the source is cited.
F_1 consists of α and β subunits alternating around a central subunit γ . In the β subunits, tight binding of $ADP + P_i$ occurs at one catalytic site and ATP is released at a second. The different binding affinities may be caused by rotation of the γ subunit in the center (Fillingame 1997).	The basic sentence structure of the original text was maintained. A few words were omitted or changed, but the text is still highly similar to the original.
ATP synthase consists of a transmembrane protein (F_0), a central shaft (γ), and an F_1 head made up of α and β subunits. As protons enter F_0 , the shaft rotates, changing the conformation of the β subunits, allowing ADP and P_i to bind and be released as ATP.	The text was paraphrased, but the source of the information was not cited.

Source: From Fillingame RH. 1997. Coupling of H⁺ transport and ATP synthesis in F₁F₀-ATP synthases: glimpses of interacting parts in a dynamic molecular machine. *The Journal of Experimental Biology*, accessed 2017 Jan 19; 200: 217–224. <http://jeb.biologists.org/content/200/2/217.full.pdf.html>

The Benefits of Learning to Write Scientific Papers

Why is it valuable to learn how to write scientific papers? First, scientific writing is a systematic approach to describing a problem. By writing what you know (and what you do not know) about the problem, it is often possible to identify gaps in your own knowledge.

Second, the scientific method is a logical approach to answering questions. It involves coming up with a tentative solution, gathering information to become more knowledgeable about the topic, evaluating the reli-

ability of the information, testing and analyzing the data, and arriving at a reasonable conclusion. This approach can be applied to many situations in your life, from deciding which graduate school to apply to, to choosing your next cell phone or your first new car.

Third, when you learn to write lab reports, you are investing in your future. Publications in the sciences are affirmation from your colleagues that your work has merit; you have been accepted into the community of experts in your field. Even if your career path is not in the sciences, scientific writing is very logical and organized, characteristics appreciated by busy people everywhere.

Credibility and Reputation

The credibility and reputation of scientists are established primarily by their ability to communicate effectively through their written reports. Poorly written papers, regardless of the importance of the content, may not get published if the reviewers do not understand what the writer intended to say.

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 you spent learning the subject matter, but also your willingness to write according to the standards of the profession.

Model Papers

Before writing your first laboratory report, look at articles published in biology journals such as *American Journal of Botany*, *Ecology*, *The EMBO Journal*, *Journal of Biological Chemistry*, *Journal of Molecular Biology*, and *Martine Biology*. Download or 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, sample student laboratory reports are given in Chapter 6. Read the comments in the margins as you peruse the reports to familiarize yourself with the basics of scientific paper format and content, as well as purpose, audience, and tone.

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 peer reviewer for feedback, if your instructor permits it.	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).
Day 6	Arrange to meet with your peer reviewer after he/she has had time to review your paper (“writing conference”). Peer reviewer reviews laboratory report.	An informal discussion is useful for providing immediate exchange of ideas and concerns. 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.
Days 6–7	Hold writing conference during which the reviewer returns the first draft to the writer. Revise laboratory report.	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. 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. Before submitting papers electronically, print out and proofread the hard copy. You will be surprised at how formatting and other kinds of errors jump out at you when you read on paper instead of on screen. When you turn in assignments on paper, make sure the pages are in order and the print is legible. 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/krise/5E/> 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 “Formatting Documents” section in Appendix 1.

Computer savvy

Know your computer 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” and Appendix 2, “Making Graphs in Microsoft 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 problem that prevents you from using your computer, you should have a backup plan in place (access to another computer).

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 p. 193 in Appendix 1 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. Windows users, click **File | Options**. Mac users, click **Word | Preferences | Output and Sharing**. From there, the common sequence is **Save | Save AutoRecover Information every ___ minutes**.

TABLE 4.2 Instructions to authors of laboratory reports

Feature	Layout
Paper	8 1/2" 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.

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 phone and get off social networking sites. 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 IMWRD 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 or acronyms 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 connotations 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 make statements about *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 the Materials and Methods section, 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 turnips.

PASSIVE VOICE: The turnips were peeled and homogenized.

The sentence written in active voice is more natural and dynamic, but it shifts the emphasis from the subject, “the turnips” to “I.” Passive voice places the emphasis on the turnips, 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 as appropriate; 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 that 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 $\mu\text{L}/\text{mL}$.

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 plot 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. 89–101). 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 (for example, 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 “Preparing visuals” section on pp. 60–72.
- **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

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.

the end of the first sentence in which you describe it. See "Writing the body of the Results section" on pp. 75–80.

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 (also called XY 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

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.

- 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. 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 4.1). List the items in a logical order (e.g., sequential, alphabetical, or increasing or decreasing value). Use sentence case for the headings. Include the units in each col-

Text describing the table immediately precedes the table. Skip a line before and after the table.	<p>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.</p>	Refer to the table number in parentheses
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Table caption is positioned above table. It consists of Arabic number and title.	<p>1 space</p> <p>2 spaces (no colon or period)</p> <p>Arabic number</p> <p>Table 1 Interaction between light and hormones in the germination of light-sensitive lettuce seeds</p>	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)	<table border="1"> <thead> <tr> <th>Light treatment (μM)</th> <th>ABA (μM)</th> <th>GA (μM)</th> <th>Seed germination (%)</th> </tr> </thead> <tbody> <tr> <td>White fluorescent light</td> <td>0</td> <td>0</td> <td>92.5</td> </tr> <tr> <td></td> <td>0.05</td> <td>10</td> <td>15</td> </tr> <tr> <td></td> <td>2</td> <td>20</td> <td>8</td> </tr> <tr> <td></td> <td>8</td> <td>40</td> <td>0</td> </tr> <tr> <td>Dark</td> <td></td> <td></td> <td>25</td> </tr> <tr> <td></td> <td></td> <td></td> <td>42</td> </tr> <tr> <td></td> <td></td> <td></td> <td>63</td> </tr> <tr> <td></td> <td></td> <td></td> <td>37</td> </tr> </tbody> </table>	Light treatment (μM)	ABA (μM)	GA (μM)	Seed germination (%)	White fluorescent light	0	0	92.5		0.05	10	15		2	20	8		8	40	0	Dark			25				42				63				37	<p>Column headings include units in parentheses where appropriate</p> <p>Horizontal lines are used sparingly</p>
Light treatment (μM)	ABA (μM)	GA (μM)	Seed germination (%)																																			
White fluorescent light	0	0	92.5																																			
	0.05	10	15																																			
	2	20	8																																			
	8	40	0																																			
Dark			25																																			
			42																																			
			63																																			
			37																																			
Categories (dependent variables) are arranged in columns, not rows		No vertical lines are used																																				

Figure 4.1 Excerpt from a Results section showing a properly formatted table preceded by the text that describes the data in the table.

umn 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.

Table captions 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.

Table titles 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: Use sentence case. Do not capitalize common nouns unless they start the sentence.

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 un-descriptive 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 4.1). 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 “Tables” in Appendix 1) or Microsoft Excel (see Formatting the Spreadsheet—Tables in Appendix 2).

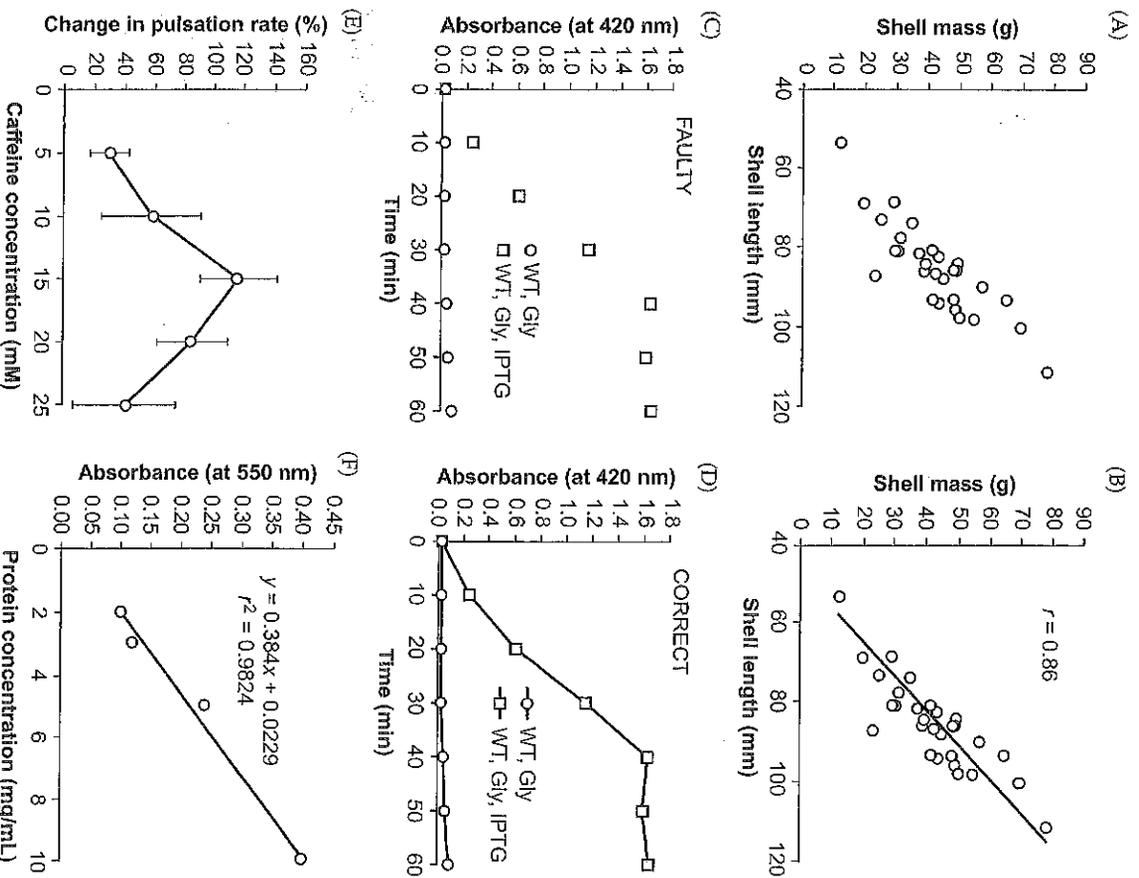
Table preparation checklist

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

Line graphs (XY graphs) and scatterplots

Line graphs display a relationship between two or more quantitative variables. To avoid confusion between the terms *line graph* and Excel's *line chart*, I will use *XY graph* when referring to line graphs. Excel's line chart is a special case of XY graph in which the independent variable is a constant interval such as time. If the values for the independent variable are not equally spaced, then Excel's scatter chart should be used to plot the data.

Figure 4.2 Different XY 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. Linear regression lines are used only in specific situations when the mathematical relationship between the two variables is clearly established.



tern in nature. Patterns may be easier to spot when the numerical data are plotted as a **scatterplot**, one kind of XY graph in which the individual data points are not connected (see Figure 4.2A). 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 relationship, scientists may superimpose a straight line on the scatterplot and display r as a measure of the strength of the relationship (see Figure 4.2B).

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 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 4.2C 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 (see Figure 4.2E). 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 XY 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 (see Figure 4.2F). 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.

Figure captions Figures are always numbered and titled *below* the visual (Figure 4.3). 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 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 for the graph in Figure 4.3 are shown here.

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

EXPLANATION: Use sentence case. Do not capitalize common nouns unless they start the sentence.

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

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

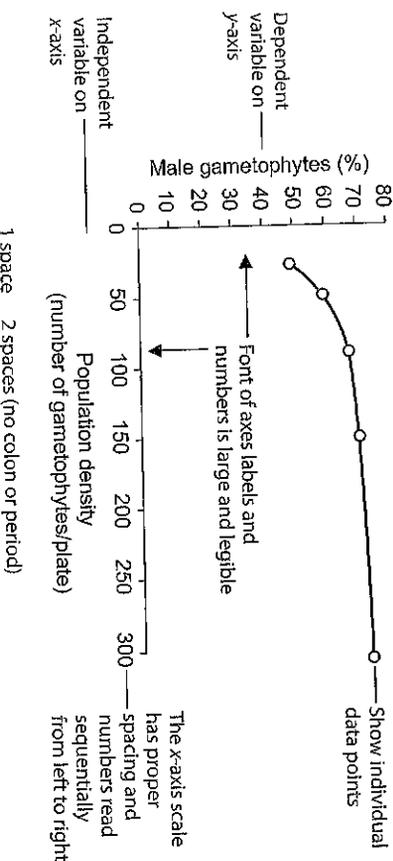


Figure caption is positioned below the figure. It consists of Arabic number and title.

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 4.3 Excerpt from a Results section showing a properly formatted figure with one line (data set): the text that describes the figure precedes it.

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 un-descriptive titles.

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

More than one data set When 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 legend (as in Figure 4.4). Place the legend without a border within the axes of the graph. This is the easiest option if you are using Excel to plot your data.

The concentration of cells in both cultures remained low for several hours (Figure 2). At about 4 hr, the concentration of the ABC strain increased rapidly and then leveled off after about 9 hr. On the other hand, it took longer for the concentration of strain XYZ to increase, but at 12 hr, the concentration was much higher than that of strain ABC.

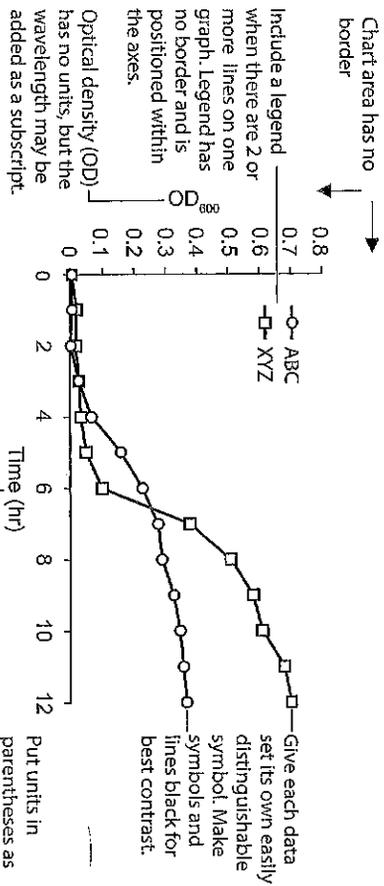


Figure 2 Growth of two fictitious strains of *E. coli* in Luria broth

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

■ 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.

Black and white or color Figures in your laboratory report should be prepared according to the guidelines specified by the Council of Science Editors (CSE Manual 2014). If this graph will be included in a written assignment such as a lab report, then make all lines, numbers, and symbols black for best contrast on a white background. If this graph will be used on a poster or in a PowerPoint presentation, colored lines make the graph visually appealing. Black is preferred for written documents because, when they are copied or printed on a black and white printer, there is no ambiguity about black on white. Colored lines turn out to be various shades of gray, which may make it hard for the reader to distinguish the numbers on the axes and the different data sets.

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 one of the variables is categorical (not quantitative)—this is the main difference between XY 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 are arranged vertically in Figure 4.5, because the category labels are short.

Figure 4.6, on the other hand, is an example of a bar graph with horizontal bars. This arrangement is more convenient to accommodate the long categorical labels that describe the rats' maternal diet and diet after weaning. The dependent variable is the time the rats spent searching for the hidden escape platform in the memory retention portion of the Morris water maze test.

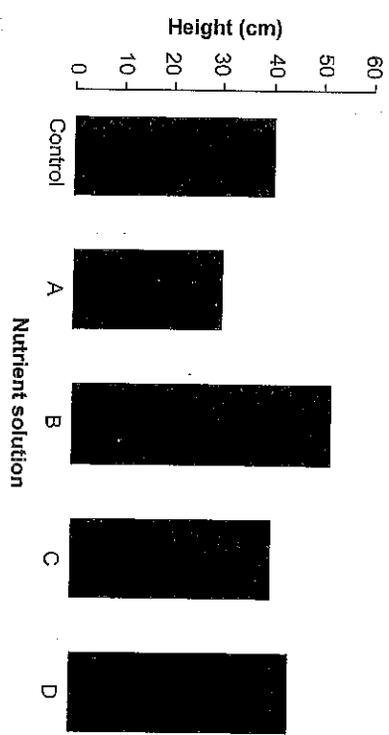


Figure 4.5 Final height of corn plants after 4-week treatment with different nutrient solutions. This figure is an example of a column graph.

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.

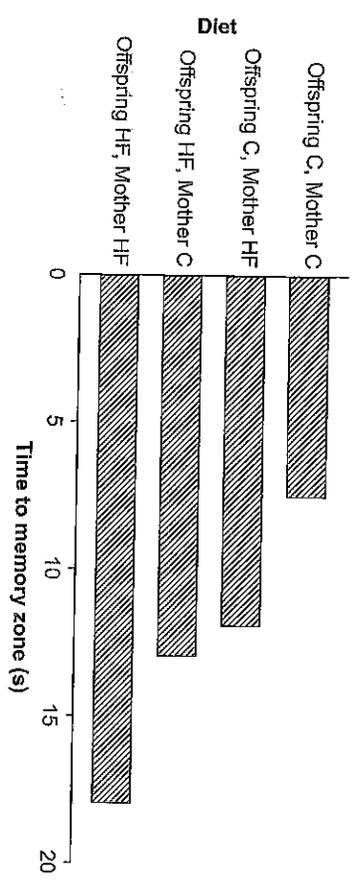


Figure 4.6 The time male rats spent swimming to the location of a submerged platform in the probe test portion of the Morris water maze. The study was conducted to determine the effect of maternal and post-weaning diet on memory retention in rats. HF = high fat diet, C = control diet. Data kindly provided by Professor Kathleen Page, Bucknell University. This figure is an example of a horizontal bar graph with long category labels and pattern bars.

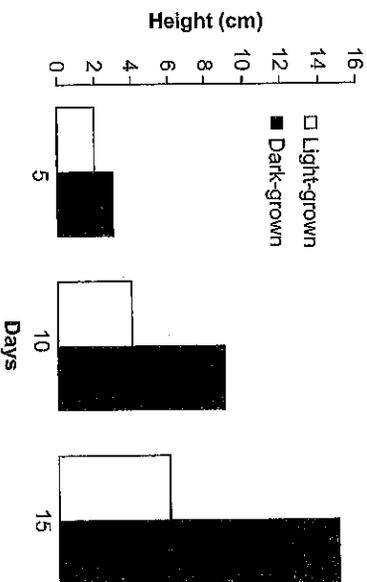


Figure 4.7 Difference in height of groups of light-grown and dark-grown bean seedlings at 5, 10, and 15 days after planting. This figure is an example of a clustered bar graph. Each bar in the cluster must be easily distinguishable from its neighbor.

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 2013 and Excel for Mac 2016 are given in Appendix 2.

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 two and eight 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 2013 and Excel for Mac 2016 are given in Appendix 2.

Figure preparation checklist

- Right type of graph
- Format correct (symbols, lines, legend, axis scale, outside tick marks, no gridlines, no border)
- Figure title descriptive
- Figure title in sentence case
- Figure caption positioned below the figure

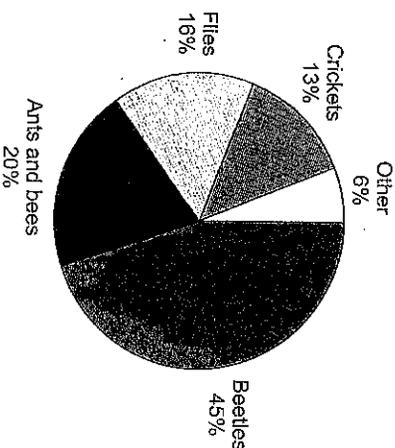


Figure 4.8 Composition of insects in backyard survey. Pie graphs are used to show data as a percentage of the total data.

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 an **XY 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.

INAPPROPRIATE: An *XY 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 an *XY graph* and connect the points with smoothed or straight lines (Figure 4.10).

(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

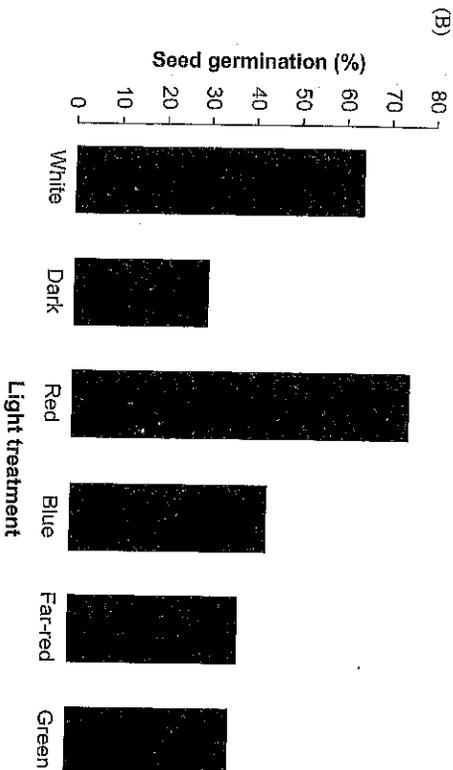


Figure 1 Effect of light treatment on percentage of light-sensitive lettuce seeds germinated after 30 hr

Figure 4.9 Example 2 data summarized in (A) a table and (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).

Writing the body of the Results section

Now that your data are displayed visually in graphs or tables, it's time to tell your audience what you consider to be important. The suggestions below will help you get started.

(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)

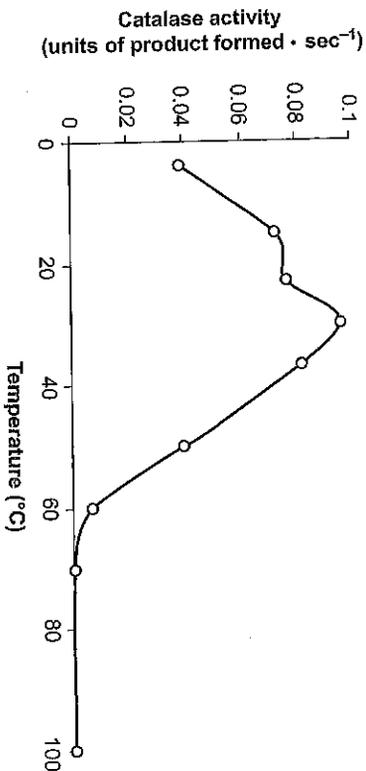


Figure 1 Effect of temperature on catalase activity

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

Use words that describe relationships that the reader can readily see in the figure How does the dependent variable change with the independent variable? Is there a recognizable mathematical relationship (for example, linear, logarithmic, or exponential) or does the trend require a more detailed description?

For example, Figure 4.4 shows an excerpt from a Results section. In this experiment, the growth of two fictitious strains of bacteria was monitored over time. The dependent variable, optical density (OD_{600}), is a measure of the concentration of cells in the culture. Consider how well each of the following sentences describes the graph.

VAGUE: The concentration of cells increased over time in both strains of *E. coli* (Figure 2).

BETTER: The concentration of cells remained low at first and then increased over time in both strains of *E. coli* (Figure 2).

BETTER YET: In both strains of *E. coli*, the concentration of cells was low for the first few hours, increased rapidly, and then leveled off after about 12 hr (Figure 2).

How much detail you use to describe the shape of the curve depends on how you plan to explain the results in the Discussion section. Pointing out key features in the Results section prepares the reader for what is to come in the discussion. The discussion is where you would correlate the changes in slope of your graph with the lag, log, and stationary phases of bacterial growth.

When there is more than one data set or category on a figure, make comparisons

TEDIOUS: In the ABC strain, concentration was low for the first few hours, increased rapidly after 4 hr, and then leveled off (Figure 2). In the XYZ strain, concentration was low for the first few hours, increased rapidly after 6 hr, and then leveled off.

BETTER: In both strains of *E. coli*, the concentration of cells was low for the first few hours, increased rapidly, and then leveled off (Figure 2). The concentration in the ABC culture began to increase after 4 hr and reached a maximum after about 12 hours. In contrast, the concentration of XYZ cells started to increase later, but reached a higher level after 12 hours.

Don't explain or interpret the results

FAULTY: Both strains of *E. coli* displayed a lag phase, followed by a log growth phase in which the cells divided rapidly, and then a stationary phase in which the growth rate was counterbalanced by the death rate (Figure 2).

EXPLANATION: The terms *lag phase*, *log growth phase*, and *stationary phase* are not marked on the graph, nor can the reader tell from the graph what the cells are doing. Save interpretations like this for the Discussion section.

Refer to the figure that shows the result you are describing

FAULTY: In both strains of *E. coli*, concentration was low for the first few hours, increased rapidly, and then leveled off.

EXPLANATION: Tell the reader where to find the data. Reference the figure in parentheses at the end of the sentence.

FIGURE AS SUBJECT: Figure 2 shows that in both strains of *E. coli*, concentration was low for the first few hours, increased rapidly, and then leveled off.

PREFERRED: In both strains of *E. coli*, concentration was low for the first few hours, increased rapidly, and then leveled off (Figure 2).

It is not incorrect to make the figure reference the subject of the sentence. However, notice how this style places the emphasis on the figure, instead of the results. The preferred style emphasizes the results, which is what the reader is looking for.

When you need more than one sentence to describe the results in a visual, refer to the figure just once in that paragraph, preferably at the beginning. That way, your readers will know right away where to look for the data, and they will assume you are describing the same figure unless you tell them otherwise.

Some XY graphs are intended to be used as tools, not to show relationships For example, standard curves are specific types of XY graphs that show absorbance as a function of concentration. Their purpose is not to

show that absorbance is proportional to concentration (Beer's Law already establishes that fact), but to allow the concentration of an unknown to be calculated from its measured absorbance. When writing about standard curves, don't describe the trend. Instead, describe how the graph was used to calculate the unknown parameter of interest.

Make every sentence meaningful

FAULTY: Concentration changed over time in both strains of *E. coli* (Figure 2).

EXPLANATION: This sentence does not say *how* concentration changed over time.

FAULTY: The results in Figure 2 show the averaged data for the whole class.

EXPLANATION: This sentence does not describe an actual result. Describe statistical methods in the Materials and Methods section. Alternatively, state that these are averaged data, and include the number of trials in the figure caption.

FAULTY: After the results were obtained, a graph was made with time on the x-axis and concentration on the y-axis, as shown in Figure 2.

EXPLANATION: This sentence states the obvious and should be deleted. Describe results, not axis labels.

Eliminate unnecessary introductory phrases. This includes phrases such as

- It was found that...
- The results showed that...
- It could be determined that...

Get to the point! State the important results in clear, concise terms.

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

Use past tense Whenever you are referring specifically to your own results, use past tense. In scientific papers, present tense is reserved for statements accepted by the scientific community as fact. At this point, your results are not yet considered "fact."

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:

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

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.

When you are asked to show your calculations, use words to describe your calculation procedure, as in the following example. Listing equations without guiding the reader through the process is like including figures without pointing out the important results. Make your writing reader-friendly!

Protein concentration of the unknown sample was determined using the equation of the biuret standard curve (Figure 1). The measured 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.

When you present a sequence of calculations like this, align the = symbol in each line.

Type equations using MS Word's Equation Editor, accessed by clicking

Equation on the **Insert** tab. Type the first equation into the box. Press

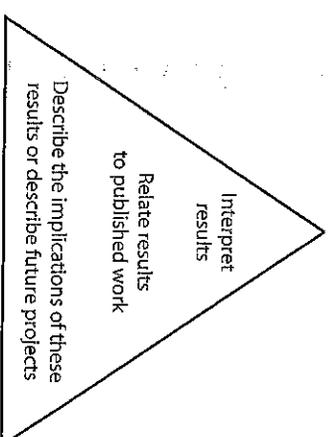
Enter. Repeat the process for each equation in the group. To align the group of equations on the equal sign, select all of the equations, right-click, and select **Align at =**. This method does not work if each line has a right-aligned equation number. In that case, the equations have to be aligned manually.

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. Ideally, there will be a one-to-one correspondence between the objectives stated in the Introduction and the interpretation and explanation of the results in the Discussion.

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.



A springboard How do you start a Discussion section? There is no specific formula, but here are some suggestions.

- Summarize your most important result and then explain what it means.
- State whether your hypothesis was negated or supported and then provide the evidence.
- Reference a published journal article and state whether or not your results supported those findings.

If, initially, you don’t know what your results mean, consult your resources. Does your lab handout give you any clues? Did your instructor talk about this topic in lecture? Don’t forget to check the index of your textbook. When you think you have an explanation, make sure you use your own words and cite your sources. No matter how you start, by the time you finish your discussion, you should have interpreted your results in the context of your objectives and the work of other scientists.

When results defy explanation 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 negatively affected your results, then say so, but don't waste a lot of words in doing so.
- Numerical values were entered incorrectly in the computer plotting program. If possible, correct the errors and repeat the analysis.
- Sample size was too small. If possible, collect more samples.
- Variability was too great to draw any conclusions. Consider redesigning your experiment.

If you can rule out these possibilities, discuss your results with your teaching assistant or instructor. Having a discussion with a knowledgeable individual may help you better understand the concepts, even if your results didn't turn out the way you expected.

Results never prove hypotheses 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.

Build your case Writing a Discussion section is an exercise in persuasive writing. You want to convince readers that your conclusions are valid. To do so requires substantiating statements with experimental evidence and referencing the work of other researchers.

To illustrate this approach, let's look at a study on the effect of human activities on the biodiversity of gastropods in rocky intertidal areas in southern California (Roy *et al.* 2003).[†] The authors suggested that trampling,

[†]Roy K, Collins AG, Becker BJ, Begovic E, Engle JM. 2003. Anthropogenic impacts and historical decline in body size of rocky intertidal gastropods in southern California. Ecology Letters 6: 205–211.

shell collecting, and harvesting of these mollusks for food or bait caused a decrease in body size over time. To test this hypothesis, the authors examined museum shell collections dating back to the late 1800s, and they also

Chronology of the Discussion section	Rationale
Authors state that adults collected prior to 1960 were larger than those surveyed more recently.	This statement follows up on an observation made in the Introduction, that humans tend to harvest or collect large specimens.
Data are presented in Figure 2: Museum specimens collected before 1960 were significantly larger than those collected between 1961 and 1980 and those surveyed in the field.	Results support the first statement.
Data are presented in Table 1: There was a decrease in median size and in the size of the largest individuals.	Results provide additional support for the first statement.
Authors propose a counterargument: Another factor, such as climate change, could be responsible for the decrease in size.	This statement shows that the authors considered other explanations for the results.
Authors suggest a way to test the counterargument: If the decrease in body size is due to human activities, then study sites in which human activity is prohibited should have larger sized mollusks.	The authors propose a testable hypothesis to differentiate the effect of human activities and non-human activities.
Data are presented in Figure 3: Protected sites had larger individuals.	Results support the human activities hypothesis.
Authors compare their findings to those of other researchers: Similar results were found for other species in California (3 papers cited). Similar results were found for species in other parts of the world (5 papers cited).	Shows that the results of the current study support previous work (an indication that the results are trustworthy). Shows that the authors are aware of other studies in this field; they acknowledge the work of the other researchers.
Authors describe future research: Investigate all possible reasons why large gastropods are disappearing from the southern CA coast; investigate ways to reverse negative human impact.	The authors recognize that there may be more than one reason why body size is declining. Future work may test alternative hypotheses.

surveyed rocky intertidal sites where some of the museum specimens had been collected. Some of the survey sites were protected from human activities; at those sites, collection of invertebrates was prohibited.

In summary, this discussion is well organized, and the authors provide compelling evidence for their conclusions. Potentially controversial statements are supported with experimental results. Counterarguments were considered and refuted. References to other published papers enhance the credibility of this study.

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 initial velocity of the reaction *was* zero at temperatures between 60 °C and 90 °C (Figure 1).

EXPLANATION: Past tense signifies that you are describing your own results.

PRESENT TENSE: At high temperatures, there is no enzymatic activity because the enzymes *are* denatured.

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

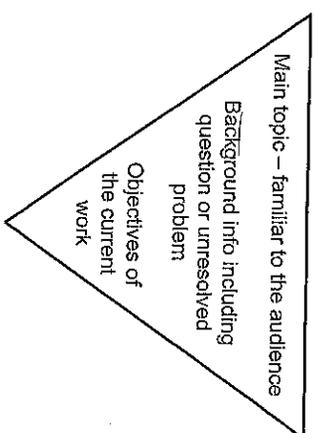
Compare your results with those in the literature Do your results agree with those in published papers? If so, then your work supports the existing body of knowledge. If not, could a different method account for a conflicting result? If warranted, discuss possible reasons why your results did not turn out as expected.

Describe future work You might propose hypotheses and experiments that build on your results.

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 study or experiment into perspective. What was already known about the topic? Were there any unanswered questions? Why did you carry out this work?

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. The author then quickly **narrows down the topic and provides background information** from the literature. The author then sets the stage for the current study by stating **any unanswered questions or inconsistencies** with previous work. Finally, in the last paragraph of the Introduction section, the author states the **objectives of the current work**. Specific hypotheses may be included if the study lends itself to hypothesis testing.

Start at the end Deciding how much background information to include is a daunting task. To make this task slightly less daunting, write your **introduction in reverse order**. In other words, **start with the objectives** and then gradually fill in the *minimum* amount of information your reader would need to understand why you chose those particular objectives. You may already have directly or indirectly addressed your objectives in the Discussion section. In that case, transcribe those sentences into the Introduction section. Alternatively, get inspiration from looking at the variables on the figures in the Results section. XY graphs typically show the effect of the *x*-axis variable on the *y*-axis variable. Photographs are used to show relationships between form and function. Flow diagrams illustrate processes. Gel images show bands that represent the size and amount of a particular nucleic acid or protein. Maps show distributions. Phylogenetic trees show evolutionary relationships. By studying the relationships, patterns, and structures shown in the figures and tables, you should be able to identify the specific objectives of your study.

Now work backward from your objectives. **What concepts would the reader need to be reminded of for these objectives (or specific hypotheses) to make sense?** For example, if you set out to determine how tem-

perature affects the rate of a particular enzyme-substrate reaction, the reader would need to know how enzyme and substrate molecules interact and how temperature affects the motion of molecules. **How much detail should you include about these broad concepts?** Less is better. In other words, provide just enough detail to prepare your readers for what is to come in the Results and Discussion sections. Include only the details that are directly relevant to your study. Do not give exhaustive reviews of the topic, otherwise you risk exhausting your reader! A well-written introduction leaves readers satisfied that they understand why the experiment was done and what the author hoped to accomplish.

When you provide background information, be sure to cite your sources, especially when the information is not common knowledge (to determine what is common knowledge, see p. 44 in Chapter 3). Citing sources not only makes your statements more credible, it allows readers to find additional information on the topic of your paper.

Finally, write the opening sentence. This may be the most difficult part of the introduction to write. To help you do so, focus on your readers. Who are they and what are they likely to know about this topic? Come up with several opening sentences and then evaluate each sentence critically in terms of the level of your audience. Choose an opening sentence that is neither too simplistic nor too technical.

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.

FACT: Peroxidase is completely denatured at temperatures above 80 °C (Duarte-Vázquez *et al.*, 2003).

On the other hand, 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.

OBJECTIVES: The purpose of this experiment *was* to determine the effect of temperature on peroxidase activity.

If the experiment lends itself to hypothesis testing, then state your hypothesis using a mixture of tenses. Notice how tenses are used in the following examples.

HYPOTHESIS: We hypothesized [past tense] that enzyme activity will increase [future tense] with temperature up to a point.

HYPOTHESIS: We expected [past tense] enzyme activity to increase [present tense] with temperature up to a point.

HYPOTHESIS: Enzyme activity is or was [either present or past tense is appropriate] expected to increase with temperature up to a point.

Voice Active voice is preferred because it makes sentences shorter and more direct. But voice can also change the emphasis of a sentence, as illustrated by the following examples:

ACTIVE VOICE: Human activities are threatening the extinction of many species.

PASSIVE VOICE: The extinction of many species is threatened by human activities.

If your point is to emphasize *the role of human activities* in species extinctions, then active voice makes the stronger statement. If your focus is on *species extinction*, then passive voice may be more appropriate.

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 un-descriptive 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:

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.

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

Here is another example in which the title is made more descriptive by removing unnecessary words and adding the specific variable that was manipulated:

FAULTY: Explanation of seed germination in *H. vulgare*

EXPLANATION: Avoid using "filler phrases" such as "explanation of," "analysis of," and "study of." Give the common name and the scientific name of the organism for the reader's benefit. Focus on the specific aspect of seed germination that you studied.

REVISION: Effect of gibberellic acid concentration on starch remaining in the endosperm of barley (*Hordeum vulgare*) seeds

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 reference**) 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 (2014) 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 reference* 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*, antheridium may be related to the gibberellins." **Do not use this style in your lab reports!**

Another difference between citations in the humanities and in scientific papers is that direct quotations are almost never used in the latter. Instead, write the information from the source text in your own words and then cite the source (see p. 45 in Chapter 3).

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 authors' names; 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 reference 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 reference and the end reference and use one system consistently throughout any given paper.

Finally, do not list sources in the end reference list that 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 reference* 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 The number of authors determines how the source is 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 <i>et al.</i> (year) found that...	(first author's last name and others, year) or <i>et al.</i> instead of <i>and others</i>

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 reference* 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. For each reference, list the authors' names in the order they appear on the title page. 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 references and their corresponding end references are given in Table 4.6. See The CSE Manual (2014) and Patrias (2007) for examples of many other kinds of sources.

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

	Name-Year End Reference System
Journal article	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 <i>et al.</i> or <i>and others</i> 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 <i>editors</i> . 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.
	Citation-Sequence End Reference System
Journal article	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 <i>et al.</i> or <i>and others</i> 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 <i>editors</i> . 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.

The Citation-Sequence system

The *in-text reference* 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.

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
3 or more authors	IN-TEXT REFERENCES Gametophytes of the tropical fern <i>Ceratopteris richardii</i> (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).
2 authors	IN-TEXT REFERENCES Gametophytes of the tropical fern <i>Ceratopteris richardii</i> (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).
1 author	IN-TEXT REFERENCES Gametophytes of the tropical fern <i>Ceratopteris richardii</i> (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).
Journal article	CORRESPONDING END REFERENCES Banks J, Webb M, Hickok L. 1993. Programming of sexual phenotype in the homosporous fern <i>Ceratopteris richardii</i> . <i>Inter. J. Plant Sci.</i> 154(4): 522-534.
Journal article	CORRESPONDING END REFERENCES Näf U. 1979. Antheridiogens and antheridial development. In: Dyer AF, editor. <i>The Experimental Biology of Ferns</i> . London: Academic Press. pp. 436-470.
Journal article	CORRESPONDING END REFERENCES Näf U, Nakanishi K, Endo M. 1975. On the physiology and chemistry of fern antheridiogens. <i>Bot. Rev.</i> 41(3): 315-359.
Book	CORRESPONDING END REFERENCES Treshow M. 1970. <i>Environment and Plant Response</i> . New York: McGraw-Hill. 250 p.
Journal article	CORRESPONDING END REFERENCES Warne T, Hickok L. 1989. Evidence for a gibberellin biosynthetic origin of <i>Ceratopteris</i> antheridiogen. <i>Plant Physiol.</i> 89(2): 535-538.
	Citation-Sequence System
Journal article	IN-TEXT REFERENCES Gametophytes of the tropical fern <i>Ceratopteris richardii</i> (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).
Journal article	CORRESPONDING END REFERENCES 1. Näf U. Antheridiogens and antheridial development. In: Dyer AF, editor. <i>The Experimental Biology of Ferns</i> . London: Academic Press: 1979. pp. 436-470.
Journal article	CORRESPONDING END REFERENCES 2. Näf U, Nakanishi K, Endo M. On the physiology and chemistry of fern antheridiogens. <i>Bot. Rev.</i> 1975 Jul-Sep; 41(3): 315-359.
Journal article	CORRESPONDING END REFERENCES 3. Banks J, Webb M, Hickok L. Programming of sexual phenotype in the homosporous fern <i>Ceratopteris richardii</i> . <i>Inter. J. Plant Sci.</i> 1993 Dec; 154(4): 522-534.
Journal article	CORRESPONDING END REFERENCES 4. Warne T, Hickok L. Evidence for a gibberellin biosynthetic origin of <i>Ceratopteris</i> antheridiogen. <i>Plant Physiol.</i> 1989 Feb; 89(2): 535-538.
Book	CORRESPONDING END REFERENCES 5. Treshow M. <i>Environment and Plant Response</i> . New York: McGraw-Hill: 1970. 250 p.
	Pagination is optional. If present, this is the total number of pages in the book, not the pages from which information was cited.

SUPERSCRIPED There are four commonly used methods for

ENDNOTE: determining protein concentration: the biuret method¹, the Lowry method², the Coomassie Blue (CB) dye-binding method³, and the bicinchoninic acid (BCA) assay⁴.

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 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 references and their corresponding end references are given in Table 4.6. See The CSE Manual (2014) and Patrias (2007) for examples of many other kinds of sources.

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 references* 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 reference* 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 2014).

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 reference includes the authority, the date, and the words "personal communication" or "unreferenced." For example:

Most viruses affecting honey bees have genomes composed of RNA rather than DNA (M. Pizzorno, personal communication, 2016 Sept 22).

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

Internet sources

In the previous section you learned that the in-text reference 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 (2014) 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 reference and end reference format for an online journal article. For a comprehensive discussion of Internet citation formats along with many examples, see Patrias (2007).

The problem with sources on the Internet is that they may disappear at any time or their URL may change. To provide a persistent link to online articles and books, many publishers include a DOI (digital object identifier) on the first page of the publication (Figure 4.11). The DOI consists of a unique string of numbers and letters that, when pasted into a browser, leads directly to that publication. According to the APA (American Psychological Association) style manual, which is commonly used in the social sciences, when a DOI is given, the DOI rather than the URL should be included in the end reference. The goal is to get the reader to the source quickly and reliably.

SUPERSCRIBED

There are four commonly used methods for determining protein concentration: the biuret method¹, the Lowry method², the Coomassie Blue (CB) dye-binding method³, and the bichromonic acid (BCA) assay⁴.

ENDNOTE:

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

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 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 references and their corresponding end references are given in Table 4.6. See The CSE Manual (2014) and Patrias (2007) for examples of many other kinds of sources.

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 references* 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 reference* 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 2014).

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 reference includes the authority, the date, and the words "personal communication" or "unreferenced." For example:

Most viruses affecting honey bees have genomes composed of RNA rather than DNA (M. Pizzorno, personal communication, 2016 Sept 22).

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

Internet sources

In the previous section you learned that the in-text reference 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 (2014) 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 reference and end reference format for an online journal article. For a comprehensive discussion of Internet citation formats along with many examples, see Patrias (2007).

The problem with sources on the Internet is that they may disappear at any time or their URL may change. To provide a persistent link to online articles and books, many publishers include a DOI (digital object identifier) on the first page of the publication (Figure 4.11). The DOI consists of a unique string of numbers and letters that, when pasted into a browser, leads directly to that publication. According to the APA (American Psychological Association) style manual, which is commonly used in the social sciences, when a DOI is given, the DOI rather than the URL should be included in the end reference. The goal is to get the reader to the source quickly and reliably.

1 Author(s)
2 Date of publication
3 Title of journal
4 Volume and issue number
5 Inclusive page numbers
6 Date updated, date accessed
7 Date accessed
8 Inclusive page numbers

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 or (8) the DOI (digital object identifier) and the date accessed in the end reference.

When URLs are used in text, they do *not* need special formatting. They do not need to be enclosed in angle brackets (< >) and they do *not* need to be underlined and in color. Every character in a URL is significant, as are spaces and capitalization. Very long URLs can be broken before a punctuation mark (like -, hyphen, underscore, period, forward slash/backslash, or pipe |). The punctuation mark is then moved to the next line.

Journal articles

The *in-text reference* 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 2014). 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. **[date updated, date accessed]**; Volume(issue); Inclusive page numbers. 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:

Warishi 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*. [accessed 2016 Sept 22]; 275: 32919–32924. <http://www.jbc.org/content/275/42/32919.long>

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. Year and month **[date updated; date accessed]**; Volume(issue); Inclusive page numbers. URL

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

14. Warishi 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*. 2000 Oct [accessed 2012 Oct 29]; 275(42): 32919–32924. <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 accessed]. 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 accessed]. URL

As an example, the homepage of the BLAST database is shown in Figure 4.12. The nucleotide blast, protein blast, blastx, and tblastn databases are individual websites within the larger BLAST website. When citing websites within websites, the following rule applies: Always cite the most

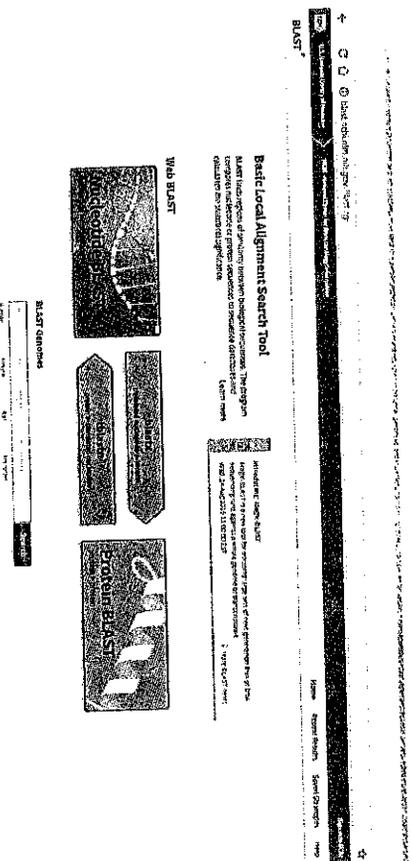


Figure 4.12 Homepage for the National Center for Biotechnology Information's BLAST database. To search for a specific nucleotide sequence, use nucleotide blast; one of the databases within the BLAST database.

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): U.S. National Library of Medicine, National Center for Biotechnology Information. [accessed 2016 Sept 20]. <http://blast.ncbi.nlm.nih.gov/Blast.cgi>

In **Citation-Sequence** format:

1. nucleotide blast [database on the Internet]. Bethesda (MD): U.S. National Library of Medicine, National Center for Biotechnology Information. [accessed 2016 Sept 20]. <http://blast.ncbi.nlm.nih.gov/Blast.cgi>

The *in-text reference* for a database 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 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 revision; and the date accessed (CSE Manual 2014). An example of an *in-text reference* 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 [accessed 2016]).

Homepages

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

Title of Homepage. Date of publication. Edition. Place of publication: publisher; [date updated; date accessed]. URL

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

Number of the citation. Title of Homepage. Edition. Place of publication: publisher; date of publication [date updated; date accessed]. URL

An example of a homepage is shown in Figure 4.13. All of the information required to cite this source is readily located. When the date of publication is not specified, the order of preference is the copyright date; the

The screenshot shows the homepage for the National Academies of Sciences, Engineering, and Medicine, specifically the 'STEM CELLS' section. The page has a dark header with the organization's name and 'STEM CELLS' in large white letters. A navigation menu includes 'Home', 'National Academies Guidelines', 'Reports', 'Stem Cell Basics', 'ES/RO Committee', and 'About'. Below the header, there is a search bar and a 'Featured' section with a thumbnail image and the text 'A primer from the National Academy of Sciences'. The main content area is titled 'Welcome' and contains several articles. The first article is 'Stem cell research is being pursued in the hope of achieving major medical breakthroughs...'. The second article is 'Guidelines for Human Embryonic Stem Cell Research' with a sub-section 'Research' and a sub-section 'Stem Cell Basics'. The 'Research' section discusses the integrity of human embryonic stem cell research. The 'Stem Cell Basics' section asks 'What is a stem cell? What are the ethical concerns involved in stem cell research?'. There are also links for 'Events Related to the Activity', 'Submit Comments on the Guidelines', and 'Sign Up for E-mail Updates'.

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

date of modification, update, or revision; and the date accessed (CSE Manual 2014). 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. c2016. Washington DC: National Academy of Sciences; [accessed 2016 Sept 20].
<http://nas-sites.org/stemcells/>

The end reference in Citation-Sequence format:

1. Stem Cells at the National Academies. Washington DC: National Academy of Sciences; c2016 [accessed 2016 Sept 20].
<http://nas-sites.org/stemcells/>

The *in-text reference* 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 accessed (CSE Manual 2014).

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 pp. 94–95). Information obtained through personal communication is cited in the in-text reference, but not in the end reference list. The in-text reference 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.

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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. Starting to write early also allows you to 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.

Slow down and concentrate

Find a quiet room where you won't be disturbed. Don't read your paper the same way you wrote it. Instead, **change its appearance** by increasing the zoom level or converting the Word document to a PDF (LR Communication Systems 1999; Corbett 2011). Even better, read a printed copy. Next, use some of your other senses to force yourself to **slow down**. For example, reading aloud involves the sense of hearing. Pointing to each word with your finger adds the sense of touch. If something doesn't sound right, trust your instincts. Figure out what is bothering you and fix the troublesome passage. Finally, **don't try to fix every kind of error in one pass**. If you do, you're sure to miss some.

Think of your audience

The rest of this chapter describes a systematic approach to revising your writing, whether for a lab report, a poster, or an oral presentation. Remember for whom you are writing and keep in mind the needs and motivations of your audience. Revise your writing with the goal of meeting or exceeding their expectations in a style that eases comprehension.

Editing

Revision can be divided into two stages: editing and proofreading. **Editing** is done first and involves reading for content and organization. The editing process proceeds from the broad to the specific. First, evaluate the overall structure of your paper. Then, read each individual section, paragraph, sentence, and word critically. And don't forget to check that the data were plotted correctly and that the description of each visual in the text is accurate. After editing is completed, **proofread** the paper. This involves correcting errors in spelling, punctuation, grammar, and overall format. This chapter provides specific guidance for each step of the revision process. The "Laboratory Report Errors" section on pp. 149–161 illustrates common errors to look out for when you revise your lab report.

Evaluate the overall structure

If your instructor provided a rubric for your lab report, use it as a checklist for content and organization. You may also wish to print out the "Biology Lab Report Checklist" on pp. 138–140 from (<http://sites.sinauer.com/Kniisey5E/>). If you are preparing a paper for submission to a journal or conference, follow the relevant *Instructions to Authors*.

Most scientific papers are divided into **standard sections**: title, authors' name(s), abstract, Introduction, Materials & Methods, Results, Discussion, and references (known as IMRD format). Readers of scientific papers like

TABLE 5.1 Checklist for section content

Section	Content
Title	Contains keywords that describe the essence of the study. "Filler" phrases like "Analysis of the...", "Study of the..." are not used.
Abstract	Contains an introduction, a brief description of the methods, results, and conclusions.
Introduction	The structure is broad to specific: The main topic is introduced on a general level. The question or unresolved problem is stated. The objectives of the current study are presented in the last paragraph. Background information is provided by citing published sources.
Materials and Methods	Contains all of the relevant details to enable another trained scientist to repeat the procedure. Routine procedures are not described.
Results	Contains text and visuals. The descriptive text precedes each visual and includes a reference to the figure or table number. The text describes the results shown in each visual. The results are not explained or interpreted. Visuals include graphs, tables, photos, gel images, and so on, which contain the numerical or descriptive data. Each visual has its own caption that begins with Figure (or Table) and a number followed by a title that can be understood apart from the text.
Discussion	The structure is specific to broad: The results are explained and interpreted. The results are compared to those in other studies, usually published journal articles. If warranted, there may be a discussion of why the results in the current study are important or how these results contribute to our understanding of the topic.
References	The full reference is given for each source cited in the text. References that have not been cited are not listed.

this format because they know where to look to find certain kinds of information. Confirm that these sections are in the **right order** in your paper. Then check that each section has the **appropriate content** (Table 5.1) by underlining each component on the printed pages or highlighting them on the computer screen (Hofmann 2014).

Do the math at least twice

Double-check your calculations and spreadsheet data entries. A mistake at this stage will have a negative domino effect, resulting in inaccurate figures or tables and a faulty discussion and interpretation of the results.

Organize each section

The phrases you underlined when you checked for content should provide a rough outline of each section. Do the **most important topics stand out**? Does the **order of the topics make sense** chronologically or sequentially? Is the order what your audience expects (for example, are the topics arranged from broad to specific in the Introduction section and specific to broad in the Discussion section)? Rearrange paragraphs so that the important topics can be identified easily, in an order that makes sense.

Make coherent paragraphs

Each paragraph should focus on only one topic Make the topic sentence the first sentence in the paragraph. Follow the topic sentence with supporting sentences that directly relate to the main idea.

Arrange the sentences in a logical order Different strategies can be used depending on the section of the scientific paper. For example, in the Materials and Methods section, it makes sense to describe the procedure *sequentially* (in the order the steps were carried out).

EXAMPLE: Barley seeds were surface sterilized with 10% bleach. Then they were cut in half, keeping the endosperm portion and discarding the embryo portion. Each half was placed cut side down on three pieces of sterile filter paper that had been soaked in 3.5 mL of HEPES-EGTA-Ca²⁺ buffer or a certain concentration of hormone solution.

Chronological sentence order might be used in the Introduction section to describe the sequence of events leading up to our current state of knowledge about a topic.

EXAMPLE: Germination begins when a seed imbibes water. Early studies on barley seeds showed that the hormone gibberellic acid (GA) is involved in this process (Paleg 1960; Yomo 1960). Varner (1964) demonstrated that the enzymes that digest starch into sugars are produced in the aleurone layer. For the past 5 decades, it was suspected that GA binds to a receptor on the surface of the aleurone cells, but how the protein subunits in the receptor function in signal transduction was discovered only recently (Ueguchi-Tanaka et al. 2005).

General-to-specific is another way to arrange sentences in the introduction. In this approach, the paragraph starts with a general idea that is then supported by details or examples.

EXAMPLE: Germination begins when a seed imbibes water. Water triggers the release of gibberellic acid (GA) from the embryo. The hormone diffuses through the endosperm and binds to receptors on the plasma membrane of the aleurone cells. Through a signal transduction pathway that is not fully understood, digestive enzymes are activated and released into the endosperm. One of those enzymes is α -amylase, which metabolizes starch into its sugar subunits.

On the other hand, *specific-to-general* is the order expected in the Discussion section. As shown in the following example, the paragraph begins with a brief recapitulation of a specific result. Subsequent sentences explain the result based on our current understanding of the topic.

EXAMPLE: Embryoless half-seeds exposed to higher concentrations of gibberellic acid had a lower percentage of starch remaining after one week (Figure 2). Gibberellic acid is known to induce the production of α -amylase, an enzyme that hydrolyzes starch (Lovegrove and Hookey 2000). During germination, gibberellic acid, produced by the embryo, binds to receptors in the aleurone layer and activates α -amylase, which then degrades the starch in the endosperm into glucose, which provides the energy for the embryo to grow.

Use signal words and phrases to guide readers from one sentence to the next Signal words and phrases (also called **transitions**) help readers see relationships between sentences. Smooth transitions help readers to follow the writer's thought process, thereby increasing comprehension. Consider the following example:

FAULTY: Catalase is an enzyme that breaks down hydrogen peroxide in both plant and animal cells. Low or high temperature can lower the rate at which the catalase can react with the hydrogen peroxide. In optimal conditions, the

enzyme functions at a rate that will prevent any substantial buildup of the toxin. If the temperature is too low, the rate will be too slow, but high temperatures lead to the denaturation of the enzyme.

Where is the writer going with this paragraph? The sentences do not seem to flow because there is no guidance from the writer on how one sentence is related to the next. To improve flow, use signal words and phrases such as *however*, *thus*, *although*, *in contrast*, *similarly*, *on the other hand*, *in addition to*, and *furthermore*. Signal words and phrases may also be key words that are repeated from one sentence to the next. Notice how the addition of transitions guides the reader step by step through this passage.

REVISION: Catalase is an enzyme that breaks down hydrogen peroxide in both plant and animal cells. One of the factors that affects the rate of this reaction is temperature. At optimal temperatures, the rate is sufficient to prevent substantial buildup of the toxic *hydrogen peroxide*. If the temperature is too low, *however*, the rate will be too slow, and hydrogen peroxide *accumulates* in the cell. *On the other hand*, high temperatures may denature the *enzyme*.

Write meaningful sentences

Each sentence should say something meaningful and not repeat what was said before (avoid redundancy). Consider the following examples.

EXAMPLE: From the data that has been gathered, a graph depicting the effect of various pH environments on the rate of catalase activity is represented. The graph displays the pH tested and the reaction rate. The data plotted is an accumulation of data from several lab sections. Through analyzing the graph I can see that there is no activity below a pH of 4 or above 10. Maximum catalase activity occurred at pH 7.

EXPLANATION: The first three sentences do not convey anything substantive about the results. Only the last two sentences contain meaningful information.

EXAMPLE: As the enzyme concentration increased, the initial velocity increased as well (Figure 3). There is an overall gradual increasing relationship between the enzyme concentration and the initial velocity. This increasing relationship seems to remain constant from the lowest concentration of 0 nM to the highest concentration which is 2 nM. This graph showed that there was a fairly increasing positive linear relationship between enzyme concentration and initial velocity.

EXPLANATION: The last three sentences say the same thing as the first sentence. The only substantive piece of information missing from the first sentence is that the trend was linear. Eliminate repetition and describe the results in as few words as possible.

To edit redundant sentences, take the best parts of those sentences and combine them into one concise sentence. Put yourself in your reader's shoes: Would you rather waste precious minutes wading through verbiage or get needed information with minimal effort?

Technical accuracy Sentences that provide background information on a topic (as in the Introduction section), describe procedures (in the Materials and Methods section), or explain results (in the Discussion section) should be based on scientific fact. When in doubt, check your references, including secondary sources such as your textbook. Furthermore, make sure that your description of the results shown in each visual is accurate. In particular, pay attention to words like *increase* and *decrease*. Check that you did not mix up the results when you describe multiple data sets plotted on one graph.

Sentence length Short sentences that contain only one idea are easy to understand. A text that contains nothing but short sentences, however, may be perceived as childish at best or hard to follow at worst. On the other hand, long, needlessly complex sentences obscure the main idea and slow comprehension. Aim for a mixture of short and long sentences in your writing. Use more words to explain a complex idea, but keep each sentence focused on just one idea.

Here are some examples of needlessly complex sentences.

FAULTY 1: *There are* two protein assays *that* are often used in research laboratories.

REVISION: Two protein assays are often used in research laboratories. (Avoid unnecessary words and phrases that “pad” a sentence.)

FAULTY 2: *It is interesting to note that* some enzymes are stable at temperatures above 60 °C.

REVISION: Some enzymes are stable at temperatures above 60 °C. (Avoid unnecessary introductory phrases.)

FAULTY 3: *The analyses were done on* the recombinant DNA to determine which piece of foreign DNA was inserted into the vector.

REVISION: The recombinant DNA was analyzed to determine which piece of foreign DNA was inserted into the vector. (Make DNA, not the *analyses*, the subject of the sentence.)

FAULTY 4: *We make the recommendation that* micropipettors be used to measure volumes less than 1 mL.

REVISION: We recommend that micropipettors be used to measure volumes less than 1 mL. (Replace sluggish noun phrases [nominalizations] with verb phrases.)

FAULTY 5: These assays alone cannot *tell* what the protein concentration of a substance is.

REVISION: These assays alone cannot determine the protein concentration of a substance. (Replace colloquial expressions with precise alternatives.)

Emphasize the subject Putting the subject at the beginning of the sentence makes the subject stand out. Position the verb close by so that there is no doubt about the subject’s action.

Active and passive voice In active voice, the subject *performs* the action. In passive voice, the subject *receives* the action. Consider the following example:

PASSIVE: The clam was opened by the sea star.
(Emphasis on *clam*)

ACTIVE: The sea star opened the clam. (Emphasis on *sea star*)

Although the meaning is the same in both sentences, notice the difference in emphasis. In active voice, the emphasis is on the performer, and the action takes place in the direction the reader reads the sentence. Active voice is recommended by most style guides for reasons that include the following:

- It sounds more natural and is easier for the reader to process.
- It is shorter and more dynamic.
- There is no ambiguity about who/what the subject of the sentence is, or about who did the action.

Consider the following example:

PASSIVE: It was concluded from this observation that...

ACTIVE: I concluded from this observation that...

Passive voice leaves the reader wondering who drew the conclusion; active voice conveys this information clearly.

While active voice is generally preferred, passive voice may be more appropriate when *what* is being done is more important than *who* is doing it. For example:

PASSIVE: Catalase was extracted from a turnip.
(Emphasis on *catalase*)

ACTIVE: I extracted catalase from a turnip. (Emphasis on *I*)

Notice the difference in emphasis. Is it really important to the success of the procedure that *you* did it, or does the emphasis belong on the catalase? A paper that contains a mixture of active and passive voice is pleasant to read. Your decision to use active or passive voice in a sentence should ultimately be determined by clarity and brevity. In other words, use active voice to emphasize the subject and the fact that the subject is performing the action. Use passive voice when the action is more important than who is doing it.

Present or past tense In scientific papers, present tense is used mainly in the following situations:

- To make generally accepted statements (for example, “Photosynthesis is the process whereby green plants produce sugars”).
- When referring directly to a table or figure in your paper (for example, “Figure 1 is a schematic diagram of the apparatus”).

- When stating the findings of published authors (for example, "Cat-alase HPII from *E. coli* is highly resistant to denaturation [Switala and others 1999]").

Past tense is used mainly in the following situations:

- To report your own work, especially in the abstract, Materials and Methods, and Results sections, because it remains to be seen if the scientific community accepts your work as fact (for example, "At temperatures above 37 °C, catalase activity *decreased* (Figure 3)").
- To cite another author's findings directly (for example, "Miller and others (1998) *found* that...").

Choose your words carefully

Words are the basic organizational unit of language. The words you choose and how you arrange them in a sentence will determine how well you convey your message to your readers. Beware of the following word-level problems:

Keep related words together Consider the following sentence taken from an English-language newspaper in Japan: "A committee was formed to examine brain death in the Prime Minister's office." Although brain death in the Prime Minister's office may be a political reality, what was really intended was, "A committee was formed in the Prime Minister's office to examine brain death."

Redundancy Redundancy means using two or more words that mean the same thing. This problem is easily corrected by eliminating one of the redundant words (Table 5.2). Along with empty phrases, redundancy is a source of wordiness, using too many words to convey an idea.

Some people think that using more words makes them sound important. In science, however, wordiness should be avoided at all costs, because it indicates that the writer can't communicate clearly. For student writers whose papers are evaluated by instructors, lack of clarity translates into a

TABLE 5.2 Examples of redundancy

Redundant	Revised
It is absolutely essential...	It is essential...
mutual cooperation	cooperation
basic fundamental concept	basic concept or fundamental concept
totally unique	unique
The solution was obtained and transferred...	The solution was transferred...

low grade. Researchers and faculty members, whose reputation depends on the number and quality of their publications, simply cannot afford *not* to write clearly, because poorly written papers may be equated with shoddy scientific methods.

Empty phrases Replace empty phrases with a concise alternative (Table 5.3). Put yourself in your reader's shoes. Which of the following two sentences (inspired by VanAlstyne 2005) would you rather read?

FAULTY: It is absolutely essential that you use a minimum number of words in view of the fact that your reader has numerous other tasks to complete at the present time.

REVISION: Write concisely, because your reader is busy.

Initially it is difficult to write in (and read) the terse, get-to-the-point style that characterizes scientific papers. With practice, however, you may come to appreciate this style because in a well-written paper, not a word is wasted. The benefit to you as a reader is that you extract a maximum amount of information from a minimum amount of text.

Ambiguous use of *this*, *that*, and *which* Ambiguity results when *this*, *that*, or *which* could refer to more than one subject.

FAULTY: The data show that the longer the enzyme was exposed to the salt solution, the lower the enzyme activity in the assay. *This* means that the salt changes the conformation of the enzyme, *which* makes it less reactive with the substrate.

EXPLANATION: The subject of *this* and *which* is unclear.

REVISION: The longer the enzyme was exposed to the salt solution, the lower the enzyme activity in the assay. Exposure to the salt solution may change the conformation of the enzyme, resulting in lower enzyme-substrate activity.

Ambiguous use of pronouns (*him*, *her*, *it*, *he*, *she*, *its*) Ambiguity results when a pronoun could refer to two possible antecedents.

TABLE 5.3 Examples of empty phrases

Empty	Concise
a downward trend	a decrease
a great deal of	much higher
a majority of	most
accounted for the fact that	because
as a result	so, therefore
as a result of	because
as soon as	when
at which time	when
at all times	always
at a much greater rate than	faster
at the present time, at this time	now, currently
based on the fact that	because
brief in duration	short, quick
by means of	by
came to the conclusion	concluded
despite the fact that, in spite of the fact that	although, though
due to the fact that, in view of the fact that	because
for this reason	so
in fact	omit this phrase

FAULTY: With time, salt changes the conformation of the enzyme, which makes it less reactive with the substrate.

EXPLANATION: It could refer to *salt* or *enzyme*. To eliminate the ambiguity, replace it with the appropriate noun phrase.

REVISION: With time, salt changes the conformation of the enzyme, so that the enzyme can no longer react with its substrate.

Word usage When you use the right words in the right situations, readers have confidence in your work. Use a standard dictionary whenever you are not sure about word usage. Consult your textbook and

TABLE 5.3 (continued)

Empty	Concise
functions to, serves to	omit this phrase
degree of	higher, more
in-a-manner similar to	like
in the amount of	of
in the vicinity of	near, around
is dependent upon	depends on
is situated in	is in
it is interesting to note that, it is worth pointing out that	omit these kinds of unnecessary introductions
it is recommended	I (we) recommend
on account of	because, due to
prior to	before
provided that	if
referred to as	called
so as to	to
through the use of	by, with
with regard to	on, about
with the exception of	except
with the result that	so that

laboratory exercise for proper spelling and usage of technical terms. The following word pairs are frequently confused in students' lab reports.

absorbance, absorptivity, observance *Absorbance* is how much light a solution absorbs; *absorptivity* is measured with a spectrophotometer. *According to Beer's law, absorptivity is proportional to concentration.* *Absorptivity* is how much moisture a diaper or paper towel can hold. *Brand A paper towels show greater absorptivity than Brand B paper towels.* *Observance* is the act of observing. *Government offices are closed today in observance of Independence Day.*

affect, effect *Affect* is a verb that means "to influence." *Temperature affects enzyme activity.* *Affect* is rarely used as a noun in biology, although it has a specific meaning in psychology. *Effect* can be

used either as a noun or a verb. When used as a noun, *effect* means "result." We studied the effect of temperature on enzyme activity. When used as a verb, *effect* means "to cause." High temperature effected a change in enzyme conformation, which destroyed enzyme activity.

alga, algae See plurals.

amount number Use amount when the quantity cannot be counted. The reaction rate depends on the amount of enzyme in the solution. Use number if you can count individual pieces. The reaction rate depends on the number of enzyme molecules in the solution.

analysis, analyses See plurals.

bacterium, bacteria See plurals.

bind, bond Bind is a verb meaning "to link." The active site is the region of an enzyme where a substrate binds. Bond is a noun that refers to the chemical linkage between atoms. Proteins consist of amino acids joined by peptide bonds. Bond used as a verb means "to stick together." This 5-minute epoxy glue can be used to bond hard plastic.

complementary, complimentary Complementary means "something needed to complete" or "matching." The DNA double helix consists of complementary base pairs: A always pairs with T, and G with C. Complimentary means "given free as a courtesy." The brochures at the visitor's center are complimentary.

confirmation, conformation Confirmation means "verification." I received confirmation from the postal service that my package had arrived. Conformation is the three-dimensional structure of a macromolecule. Noncovalent bonds help maintain a protein's stable conformation.

continual, continuous Continual means "going on repeatedly and frequently over a period of time." The continual chatter of a group of inconsiderate students during the lecture annoyed me. Continuous means "going on without interruption over a period of time." The bacteria were grown in L-broth continuously for 48 hr.

create, prepare, produce Create is to cause to come into existence. The artist used wood and plastic to create this sculpture. Prepare means

"to make ready." The protein standards were prepared from a 50 mg/mL stock solution. Produce means to make or manufacture. The reaction between hydrogen peroxide and catalase produces water and oxygen.

datum, data See plurals.

different, differing Different is an adjective that means "not alike." An adjective modifies a noun. Different concentrations of bovine serum albumin were prepared. Differing is the intransitive tense of "to differ," a verb that means "to vary." It is incorrect to replace the word *different* with *differing* in the preceding example, because *differing* implies that a single concentration changes depending on time or circumstance. This situation is highly unlikely with bovine serum albumin, which is quite stable under laboratory conditions! An acceptable use of *differing* is shown in the following example: Bovine serum albumin solutions, differing in their protein content, were prepared.

effect, affect See affect, effect.

fewer, less Use fewer when the quantity can be counted. The reaction rate was lower, because there were fewer collisions between enzyme and substrate molecules. Use less when the quantity cannot be counted. The weight of this sample was less than I expected.

formula, formulas, formulae See plurals.

hypothesis, hypotheses See plurals.

its, it's Its is a possessive pronoun meaning "belonging to it." The Bradford assay is preferred because of its greater sensitivity. It's is a contraction of "it is." The Bradford assay is preferred because it's more sensitive. (Note: Contractions should not be used in formal writing.)

less, fewer See fewer, less.

lose, loose Lose means to misplace or fail to maintain something. An enzyme may lose its effectiveness at high temperatures. Loose means "not tight." When you autoclave solutions, make sure the lid on the bottle is loose.

lowered, raised Both of these are transitive verbs, which means that they require a direct object (a noun to act on). **Wrong:** *The fish's body temperature lowered in response to the cold water.* **Right:** *The cold water lowered the fish's body temperature.*

media, medium See plurals.

observance See absorbance, absorbcency, observance.

phenomenon, phenomena See plurals.

plurals The plural and singular forms of some words used in biology are given in Table 5.4. A common mistake with these words is not making the subject and verb agree. Some disciplines treat *data* as singular, but scientists subscribe to the strict interpretation that *data* is plural. The data *show*... (not *shows*) is correct.

prepare See create, prepare, produce.

produce See create, prepare, produce.

raised, lowered See lowered, raised.

ratio, ration *Ratio* is a proportion or quotient. *The ratio of protein in the final dilution was 1:5.* *Ration* is a fixed portion, often referring to food. *The Red Cross distributed rations to the refugees.*

TABLE 5.4 Singular and plural of words frequently encountered in biology

Singular	Plural
algae	algae
analysis	analyses
bacterium	bacteria
criterion	criteria
datum (rarely used)	data
formula	formulas, formulae
hypothesis	hypotheses
index	indexes, indices
medium	media
phenomenon	phenomena
ratio	ratios

strain, strand A *strain* is a line of individuals of a certain species, usually distinguished by some special characteristic. *The *lact*-strain of *E. coli* produces a nonfunctional repressor protein.* A *strand* is a ropelike length of something. *The strands of DNA are held together with hydrogen bonds.*

than, then *Than* is an expression used to compare two things. *Collisions between molecules occur more frequently at high temperatures than at low temperatures.* *Then* means "next in time." *First 1 mL of protein sample was added to the test tube. Then 4 mL of biuret reagent was added.*

that, which Use *that* with restrictive clauses. A restrictive clause limits the reference to a certain group. Use *which* with nonrestrictive clauses. A nonrestrictive clause does not limit the reference, but rather provides additional information. Commas are used to set off nonrestrictive clauses but not restrictive clauses. Consider the following examples:

EXAMPLE 1: The Bradford assay, which is one method for measuring protein concentration, requires only a small amount of sample. (*Which* begins a phrase that provides additional information, but is not essential to make a complete sentence.)

EXAMPLE 2: Enzyme activity decreased significantly, which suggests that the enzyme was denatured at 50 °C. (*Which* refers to the entire phrase *Enzyme activity decreased significantly*, not to any specific element.)

EXAMPLE 3: The samples that had high absorbance readings were diluted. (*That* refers specifically to the samples.)

various, varying *Various* is an adjective that means "different." *Various hypotheses were proposed to explain the observations.* *Varying* is a verb that means "changing." *Varying the substrate concentration while keeping the enzyme concentration constant allows you to determine the effect of substrate concentration on enzyme activity.* Analogous to *different*, *differing*, replacing the word *various* with *varying* in the preceding example changes the meaning of the sentence. *Varying* implies that a single hypothesis

changes depending on time or circumstance. *Various* implies that different hypotheses were proposed.

Jargon and scientific terminology Jargon refers to words and abbreviations used by specialists. Whenever you use terms that may be unfamiliar to your audience, define them. Always write out the full expression when first using an abbreviation. Scientific words that you learned in class are *not* jargon and should be used in your writing. When you use scientific terminology correctly, your readers have confidence in your knowledge.

Clichés and slang Clichés are tired, worn out expressions that have no place in an exciting field like biology. Slang should not be used, because colloquial language is not appropriate in formal, written assignments like lab reports.

Gender-neutral language Years ago, it was customary, for the sake of simplicity, to use masculine pronouns to refer to antecedents that could be masculine or feminine, but that use of language is no longer accepted.

SEXIST: The clarity with which a biology student writes *this* lab reports affects *this* grade.

This practice is no longer considered to be politically correct. One solution that preserves equality, but makes sentences unnecessarily complex, is to include both masculine and feminine pronouns, as in the following example.

EQUAL BUT The clarity with which a biology student writes *his or her* lab reports affects *his or her* grade.

Two better alternatives are to make the antecedent plural (revision 1) or to rewrite the sentence to avoid the gender issue altogether (revision 2).

REVISION 1: The clarity with which biology students write *their* lab reports affects *their* grade.

REVISION 2: *Writing clearly* has a positive effect on a biology student's grade. (Change the subject from *biology* student to *writing clearly*.)

Construct memorable visuals

Visuals often make the difference in how well you convey your message to your readers or listeners. Make sure you use the appropriate visual

for the data (see pp. 60–75 in Chapter 4). Make sure every visual serves a **purpose**, because unnecessary visuals only dilute the significance of your message. Check that the **visuals are positioned in the right order** and that **each visual is described** in the text.

Proofreading: The Home Stretch

Proofreading is the last stage of revision. Like editing, it requires intense focus and slow, careful reading to find errors in format, spelling, punctuation, and grammar. Grammar refers to the rules that deal with the form and structure of words and their arrangement in sentences. See Hacker and Sommers (2016), Bullock et al. (2014), or Lunsford (2013, 2015, 2016) for a more comprehensive treatment of the subject.

Make subjects and verbs agree

We learn early on in our formal education to make the verb agree with the subject. Most of us know that *the sample was...*, but that *the samples were...* Most errors with subject-verb agreement occur when there are words *between* the subject and the verb, as in the following example.

EXAMPLE: The *kinetic energy* of molecules *is* (not *are*) lower at 6 °C than 45 °C.

EXAMPLE: The *chance* of collisions between enzyme and substrate molecules *increases* (not *increase*) under those conditions.

EXAMPLE: The enzyme has a *range* of temperatures that *is* (not *are*) optimal for activity.

When you write complex sentences, ask yourself what the subject of the sentence is. Look for the verb that goes with that subject. Then, mentally remove the words in between the two, and make the subject and its verb agree.

A second situation in which subject-verb agreement becomes confusing is when there are two subjects joined by *and*, as in the following example.

EXAMPLE: An enzyme's amino acid *sequence and* its three-dimensional *structure make* (not *makes*) the enzyme-substrate relationship unique.

Compound subjects joined by *and* are almost always plural.

A third situation involving subject-verb agreement is that when numbers are used in conjunction with units, the *quantity* is considered to be *singular*, not plural.

EXAMPLE: To extract the enzyme, 12 g of turnips was (not were) homogenized with 150 mL of cold, distilled water.

Write in complete sentences

A complete sentence consists of a subject and a verb. If the sentence starts with a subordinate word or words such as *after, although, because, before, but, if, so that, that, though, unless, until, when, where, who, or which*, however, another clause must complete the sentence.

FAULTY 1: High temperatures destroy the three-dimensional structure of enzymes. Thus changing the effectiveness of the enzyme. (The second "sentence" is a fragment.)

REVISION: High temperatures destroy the three-dimensional structure of enzymes, thus changing their effectiveness. (Combine the fragment with the previous sentence, changing punctuation as needed.)

FAULTY 2: The standard curve for the biuret assay was used to determine the protein concentration of the serial dilutions of the egg white. Although only those dilutions whose protein concentrations fell within the sensitivity range of the assay were multiplied by the dilution factor to give the original concentration of the egg white. (The second "sentence" is a fragment.)

REVISION: The standard curve for the biuret assay was used to determine the protein concentration of the serial dilutions of the egg white. Only those dilutions whose protein concentrations fell within the sensitivity range of the assay were multiplied by the dilution factor to give the original concentration of the egg white. (Delete the subordinate word[s] to make a complete sentence.)

Revise run-on sentences

Run-on sentences consist of two or more independent clauses joined without proper punctuation. Each independent clause could stand alone as a complete sentence. Run-on sentences are common in first drafts, where

your main objective is to get your ideas down on paper (or electronic media, if you use a computer). When you revise your first draft, however, use one of the following strategies to revise run-on sentences:

- Insert a comma and a coordinating conjunction (*and, but, or, nor, for, so, or yet*).
- Use a semicolon or possibly a colon.
- Make two separate sentences.
- Rewrite the sentence.

FAULTY 1: The class data for the Bradford method were scattered, those for the biuret method were closer.

REVISION A: The class data for the Bradford method were scattered, but those for the biuret method were closer. (Use a coordinating conjunction.)

REVISION B: The class data for the Bradford method were scattered; those for the biuret method were closer. (Use a semicolon.)

FAULTY 2: The readings from the spectrophotometer should show a correlation between protein concentration and absorbance, this is Beer's law, which relates absorbance to the path length of light along with molar concentration of a solute and the molar coefficient. (Fused sentence.)

REVISION A: The readings from the spectrophotometer should show a correlation between protein concentration and absorbance; this is Beer's law, which relates absorbance to the path length of light along with molar concentration of a solute and the molar coefficient. (Use a semicolon to separate the two clauses.)

REVISION B: The readings from the spectrophotometer should show a correlation between protein concentration and absorbance. This relationship is described by Beer's law, which relates absorbance to the path length of light along with molar concentration of a solute and the molar coefficient. (Make two separate sentences.)

FAULTY 3: An increase in enzyme concentration increased the reaction rate as did an increase in substrate concentration, so the concentrations of the molecules have an influence on how the enzyme reacts.

REVISION A: As enzyme concentration and substrate concentration increased, so did the reaction rate. (Rewrite the sentence. The second half of the original sentence was deleted because it says nothing meaningful)

REVISION B: Enzyme and substrate concentration influence enzyme reaction rate: an increase in enzyme or substrate concentration increased reaction rate. (Use a colon.)

Spelling

Spell checkers in word processing programs are so easy to use that there is really no excuse for *not* using them. Just remember that spell checkers may not know scientific terminology, so consult your textbook or laboratory manual for correct spelling. In some cases, the spell checker may even try to get you to change a properly used scientific word to an inappropriate word that happens to be in its database (for example, *absorbance* to *absorbency*).

The following poem is an example of how indiscriminate use of the spell checker can produce garbage:

Wrest a Spell

Eye halve a spelling chequer
It came with my pea sea
It plainly marques four my revue
Miss steaks eye kin knot sea.
Eye strike a key and type a word
And weight four it two say
Weather eye am wrong oar write
It shows me strait a weighh.
As soon as a mist ache is maid
It nose bee fore two long
And eye can put the error rite
Its rare lea ever wrong.

Eye have run this poem threw it
I am shore your pleased two no
Its letter perfect awl the weighh
My chequer tolled me sew.
— Sauce unknown

Spell checkers will also not catch mistakes of usage, for example *form* if you really meant *from*. Print out your document and proofread the hard copy carefully.

Punctuation

The purpose of punctuation marks is to divide sentences and parts of sentences to make the meaning clear. A few of the most common punctuation marks and their uses are described in this section. For a more comprehensive, but still concise, treatment of punctuation, see Hacker and Sommers (2016) or Lunsford (2013, 2015, 2016).

The comma The comma inserts a pause in the sentence in order to avoid confusion. Note the ambiguity in the following sentence:

While the sample was incubating the students prepared the solutions for the experiment.

A comma *should* be used in the following situations:

1. To connect two independent clauses that are joined by *and*, *but*, *or*, *nor*, *for*, *so*, or *yet*. An independent clause contains a subject and a verb, and can stand alone as a sentence.

EXAMPLE: Feel free to call me at home, but don't call after 9 p.m.

2. After an introductory clause, to separate the clause from the main body of the sentence.

EXAMPLE: Although she spent many hours writing her lab report, she earned a low grade because she forgot to answer the questions in the laboratory exercise.

A comma is not needed if the clause is short.

EXAMPLE: Suddenly, the power went out.

3. Between items in a series, including the last two.

EXAMPLE: Enzyme activity is affected by factors such as substrate concentration, pH, temperature, and salt.

4. Between coordinate adjectives (if the adjectives can be connected with *and*).

EXAMPLE: The students' original, humorous remarks made my class today particularly enjoyable. (*Original and humorous* makes sense.)

A comma is not needed if the adjectives are cumulative (if the adjectives cannot be connected with *and*).

EXAMPLE: The three tall students look like football players. (It would sound strange to say *three and tall students*.)

5. With *which*, but not *that* (see Word usage; that, which, p. 119)

6. To set off conjunctive adverbs such as *however*, *therefore*, *moreover*, *consequently*, *instead*, *likewise*, *nevertheless*, *similarly*, *subsequently*, *accordingly*, and *finally*.

EXAMPLE: Instructors expect students to hand in their work on time; however, illness and personal emergencies are acceptable excuses.

7. To set off transitional expressions such as *for example*, *as a result*, *in conclusion*, *in other words*, *on the contrary*, and *on the other hand*.

EXAMPLE: Chuck participates in many extracurricular activities in college. As a result, he rarely gets enough sleep.

8. To set off parenthetical expressions. Parenthetical expressions are statements that provide additional information; however, they interrupt the flow of the sentence.

EXAMPLE: Fluency in a foreign language, as we all know, requires years of instruction and practice.

A comma *should not* be used in the following situations.

1. After *that*, when *that* is used in an introductory clause

EXAMPLE: The student could not believe that he lost points on his laboratory report because of a few spelling mistakes.

2. Between cumulative adjectives, which are adjectives that would not make sense if separated by the word *and* (see Item 4 in preceding list)

The semicolon The semicolon inserts a stop between two independent clauses not joined by a coordinating conjunction (*and*, *but*, *or*, *nor*, *for*, *so*, or *yet*). Each independent clause (one that contains a subject and a verb) could stand alone as a sentence, but the semicolon indicates a closer relationship between the clauses than if they were written as separate sentences.

EXAMPLE: Outstanding student-athletes use their time wisely; this trait makes them highly sought after by employers.

A semicolon is also used to separate items in a series in which the items are already separated by commas.

EXAMPLE: Participating in sports has many advantages. First, you are doing something good for your health; second, you enjoy the camaraderie of people with a common interest; third, you learn discipline, which helps you make effective use of your time.

The colon The colon is used to call attention to the words that follow it. Some conventional uses of a colon are shown in the following examples.

Dear Sir or Madam:
5:30 P.M.
2:1 (ratio)

In references, to separate the place of publication and the publisher, as in Sunderland (MA): Sinauer Associates, Inc.

A colon is often used to set off a list, as in the following example.

EXAMPLE: Catalase activity has been found in the following vegetables: turnips, leeks, parsnips, onions, zucchini, carrots, and broccoli.

A colon *should not* be used when the list follows the words *are*, *consist of*, *such as*, *including*, or *for example*.

EXAMPLE: Catalase activity has been found in vegetables such as turnips, leeks, parsnips, onions, zucchini, carrots, and broccoli.

The period The period is used to end all sentences except questions and exclamations. It is also used in American English for some abbreviations, for example, *Mr., Ms., Dr., Ph.D., i.e., and e.g.*

Parentheses Parentheses are used mainly in two situations in scientific writing: to enclose supplemental material and to enclose references to visuals or sources. Use parentheses sparingly because they interrupt the flow of the sentence.

EXAMPLE: Human error (failure to make the solutions correctly, arithmetic errors, and failure to zero the spectrophotometer) was the main reason for the unexpected results.

REFERENCE TO VISUAL: There was no catalase activity above 70 °C (Figure 1).

CITATION-SEQUENCE SYSTEM: C-fern spores do not germinate in the dark (1).

NAME-YEAR SYSTEM: C-fern spores do not germinate in the dark (Cooke and others 1987).

The dash The dash is used to set off material that requires special emphasis. To make a dash on the computer, type two hyphens without a space before, after, or in between. In some word processing programs, the two hyphens are automatically converted to a solid dash.

Similar to commas and parentheses, a pair of dashes may be used to set off supplemental material.

EXAMPLE: Human error—failure to make the solutions correctly, arithmetic errors, and failure to zero the spectrophotometer—was the main reason for the unexpected results. (If the word processing program has been set up to convert the two hyphens to a solid dash, the sentence looks like this: Human error—failure to make... spectrophotometer—was the main reason...)

Similar to a colon, a single dash calls attention to the information that follows it.

EXAMPLE: Catalase activity has been found in many vegetables—turnips, leeks, parsnips, onions, zucchini, carrots, and broccoli.

If an abrupt or dramatic interruption is desired, use a dash. If the writing is more formal or the interruption should be less conspicuous, use one of the other three punctuation marks. However, do not replace a pair of dashes with commas when the material to be set off already contains commas, as in the following example.

EXAMPLE: The instruments that she plays—oboe, guitar, and piano—are not traditionally used in the marching band.

Abbreviations

The CSE Manual (2014) defines standard abbreviations for authors and publishers in the sciences and mathematics. Some of the terms and abbreviations that you may encounter in introductory biology courses are shown in Table 5.5. Take note of spacing, case (capital or lowercase letters), and punctuation use. Except where noted, the symbols are the same for singular and plural terms (for example, 30 min *not* 30 mins).

Widely known abbreviations such as DNA and ATP do not have to be defined. But abbreviations known only to specialists should be defined the first time they are used.

EXAMPLE: CRISPR (clustered regularly interspaced short palindromic repeats) technology makes it possible to edit segments of DNA in a precise and predictable fashion.

Numbers

Numbers are used for quantitative measurements. In the past, numbers less than 10 were spelled out, and larger numbers were written as numerals. The modern scientific number style recommended in the CSE Manual (2014) aims for a more consistent usage of numbers. The rules are as follows:

1. Use numerals to express any *quantity*. This form increases their visibility in scientific writing, and emphasizes their importance.
 - Cardinal numbers, for example, 3 observations, 5 samples, 2 times
 - In conjunction with a unit, for example, 5 g, 0.5 mm, 37 °C, 50% 1 hr. Pay attention to spacing, capitalization, and punctuation (see Table 5.5).
 - Mathematical relationships, for example, 1:5 dilution, 1000× magnification, 10-fold

TABLE 5.5 Standard abbreviations in scientific writing

Term	Symbol or Abbreviation	Example
Latin words and phrases [The CSE Manual (2014) recommends that Latin words be replaced with English equivalents.]		[The Latin word may be replaced with the English equivalent given in brackets.]
<i>circa</i> (approximately)	ca.	The lake is ca. [approx.] 300 m deep.
<i>et alii</i> (and others)	et al.	Jones et al. [and others] (1999) found that ...
<i>et cetera</i> (and so forth)	etc.	pH, alkalinity, etc. [and other characteristics] were measured.
<i>exempli gratia</i> (for example)	e.g.	Water quality characteristics (e.g., [for example,] pH, alkalinity) were measured.
<i>id est</i> (that is)	i.e.	The enzyme was denatured at high temperatures, i.e., the enzyme activity was zero. [Because the enzyme was denatured at high temperatures, the enzyme activity was zero.]
<i>nota bene</i> (take notice)	NB	NB [Important!]: Never add water to acid when making a solution.
LENGTH		
nanometer (10^{-9} meter)	nm	Note: There is a space between the number and the abbreviation. There is no period after the abbreviation.
micron (10^{-6} meter)	μm	
millimeter (10^{-3} meter)	mm	
centimeter (10^{-2} meter)	cm	
meter	m	450 nm, 10 μm , 2.5 cm
MASS		
nanogram (10^{-9} gram)	ng	Note: There is a space between the number and the abbreviation. There is no period after the abbreviation.
microgram (10^{-6} gram)	μg	
milligram (10^{-3} gram)	mg	
gram	g	
kilogram (10^3 gram)	kg	450 ng, 100 μg , 2.5 g, 10 kg

TABLE 5.5 (continued)

Term	Symbol or Abbreviation	Example
VOLUME		
microliter (10^{-6} liter)	μl or μL	Note: There is a space between the number and the abbreviation. There is no period after the abbreviation.
milliliter (10^{-3} liter)	ml or mL	
liter	l or L	
cubic centimeter (ca. 1 mL)	cm^3	450 μl or 450 μL , 0.45 ml or 0.45 mL, 2 l or 2 L
TIME		
seconds	s or sec	
minutes	min	Note: There is a space between the number and the abbreviation. There is no period after the abbreviation.
hours	h or hr	
days	d	60 s or 60 sec, 60 min, 24 h or 24 hr, 1 d
CONCENTRATION		
molar (U.S. use)	M	TBS contains 0.01 M Tris-HCl, pH 7.4 and 0.15 M NaCl.
molar (SI units)	mol L ⁻¹	
parts per thousand	ppt	Brine shrimp can be raised in 35 ppt seawater.
OTHER		
degree(s) Celsius	°C	15 °C (there is a space between number and symbol)
degree(s) Fahrenheit	°F	59 °F (there is a space between number and symbol)
diameter	diam.	pipe diam. was 10 cm
figure, figures	Fig., Figs.	As shown by Fig. 1, ...
foot-candle	fc or ft-c	500 fc or 500 ft-c
maximum	max	The max enzyme activity was found at 36 °C.
minimum	min	The min temperature of hatching was 12 °C.
mole	mol	
percent	%	95% (there is no space between number and symbol)
species (sing.)	sp.	<i>Tetrahymena</i> sp.
species (plur.)	spp.	<i>Tetrahymena</i> spp.

2. Spell out numbers in the following cases:

- When the number begins a sentence, for example, “*Twelve g of turnips was (not were) homogenized.*” rather than “*12 g of turnips was homogenized.*” Alternatively, restructure the sentence so that the number does not begin the sentence. Notice that when numbers are used in conjunction with units, the quantity is considered to be singular, not plural.
- When there are two adjacent numbers, retain the numeral that goes with the unit, and spell out the other one. An example of this is *The solution was divided into four 250-mL flasks.*
- When the number is used in a nonquantitative sense, for example, *one of the treatments, the expression approaches zero, one must consider...*
- When the number is an ordinal number less than 10, and when the number expresses rank rather than quantity, for example, *the second time, was first discovered.*
- When the number is a fraction used in running text, for example, *one-half of the homogenate, nearly three-quarters of the plants.* When the precise value of a fraction is required, however, use the decimal form, for example, 0.5 L rather than *one-half liter.*
- 3. Use scientific notation for very large or very small numbers. For the number 5,000,000, write 5×10^6 , not *5 million*. For the number 0.000005, write 5×10^{-6} .
- 4. For decimal numbers less than one, always mark the ones column with a zero. For example, write 0.05, not .05.

Format

Most university writing centers and professional editors recommend proofreading your paper in multiple “passes,” looking for one kind of error in each pass (The Writing Center at UNC Chapel Hill 2014; CUNY Writing Fellows 2016; Every 2012). This strategy works particularly well for finding formatting errors, which are much easier to detect on printed pages than on the computer screen (Table 5.6). Check for potential errors in the following areas:

- Section headings
- Bulleted or numbered lists
- Figures and tables, including their in-text references
- In-text citations of outside sources
- Full references at the end of the paper

TABLE 5.6 Checklist for proofreading format

Category	Check for
Section headings	Correct order, consistent format, not separated from section body
Lists (bulleted or numbered)	Sequential numbering and consistent style, parallelism in sentence structure, consistent indentation for each level
Figures and tables	Sequential numbering in the order they are described
In-text references to figure and table numbers	Correspondence with the actual figures and tables
In-text citations	One-to-one correspondence with the end references; formatting is correct
End references	One-to-one correspondence with the in-text citations; all information is present; formatting is correct
Headers and footers (if needed)	Correct position on each page
Page numbers	Sequential (check especially after section breaks in Microsoft Word)
Typography	Consistent typeface, font size, and line spacing
■ Headers and footers	
■ Page numbers	
■ Typography	

Get Feedback

When we are engrossed in our work, we may fail to recognize that what is obvious to us is not obvious to an “outsider.” That is where feedback from someone who is familiar with the subject matter comes in handy. If your instructor allows it, ask your lab partner, another classmate, or your teaching assistant to review your paper. Return the favor by reviewing someone else’s. You may also get valuable feedback from a writing expert at your school’s writing center.

The questions your reviewer will focus on are as follows:

- Do I know what the writer is trying to accomplish with this paper? Is the purpose clear?
- What questions or concerns do I have about this paper? Are there sections that were difficult to follow? Are the organization, content, flow, and level appropriate for the intended audience?

- What suggestions can I offer the writer to help him/her clarify the intended meaning?
- What do I like about the paper? What are its strengths?

Tips for being a good peer reviewer

There are two issues with which you may struggle when you are asked to review your classmate's paper: (1) I'm not confident that I know the "right" answer or know enough about the writing process to give good suggestions, and (2) I don't want to hurt the writer's feelings. These are valid concerns, and resolving them will require, first, a willingness to learn as much about writing scientific papers as possible, and second, the attitude that if something is unclear to you, it may also be unclear to other readers. With each paper you review, you will gain more confidence in your ability to give constructive feedback. In the meantime, however, a good rule of thumb is to give the kinds of suggestions and consideration that you would like to receive on your own paper.

When reviewing electronic files, the **New Comment** and **Track Changes** commands on the Review tab in Microsoft Word are very useful (see Appendix 1, pp. 199–201). **New Comment** allows the reviewer to make a comment or query, without editing the text itself, off to the side of the main text. When **Track Changes** is turned on, the reviewer's suggested changes, typed right into the body of the text, appear in a different color. The author can then accept or reject the changes. Think of the peer review process as a team sport: the reviewer is not challenging the writer's right to be on the team. The two are working together to get the best possible result.

Here are some concrete tips for being a good peer reviewer:

- Talk to the writer about his or her objectives, questions and concerns, parts that need specific feedback, and perceived strengths and weaknesses.
- Use the "Biology Lab Report Checklist" (pp. 138–140) for content.
- Look over Table 6.2 and "A Lab Report in Need of Revision" (pp. 150–161 in Chapter 6) for common errors.
- Mark awkward sentences, spelling and punctuation mistakes, and formatting errors. Do not feel you have to rewrite individual sentences—that is the writer's job.
- Ask questions. Let the writer know where you can't follow his/her thinking, where you need more examples, where you expect more detailed analysis, and so on.

- Do not be embarrassed about making lots of comments; the author does not have to accept your suggestions. On the other hand, if you say only good things about the paper, how will the writer know whether the paper is accomplishing the desired objectives?

You can fine-tune your proofreading skills on any text. You may recognize some of your own problems in other people's writing, and, with persistence and practice, you will find creative solutions to correct these problems. **Keep a log of the problems that recur in your writing** and review them from time to time. Repetition builds awareness, which will help you achieve greater clarity in your writing.

Have an informal discussion with your peer reviewer

Sometimes the comments made by the peer reviewer are self-explanatory. Other times, however, the peer reviewer cannot respond to certain parts of the paper, because more information is required. Under these circumstances, an informal discussion between the writer and the reviewer is helpful. There are two important rules for this discussion:

- First, the writer talks and the reviewer listens. The objective is to help the writer express exactly what he/she wants to say in the paper.
- Second, the reviewer talks, in nonjudgmental terms, about which parts of the paper were readily understandable and which parts were confusing. The reviewer does not have to be an experienced writer to do this—no two people have exactly the same life experiences, and there is always something positive you can learn from looking at your writing from someone else's perspective.

Feedback from your instructor

Some instructors write comments on the hard copy of a lab report; others use electronic editing tools. When instructors grade hard copies, they usually use standard proofreading marks to save time. If you don't know what the marks mean, ask your instructor or look them up. Frequently used proofreading marks are listed in Table 6.1. A more comprehensive list is available in the CSE Manual (2014), at <http://www.biomedicaliutor.com/support-files/proofreadingmarks.pdf>, and in other printed and online sources.

Online submissions have become increasingly widespread, especially at the college level, for several reasons. Students like the convenience. Submitting assignments online does not require a printer and can be done at the last minute. When a document is stored in the cloud, it can be accessed

from a variety of devices, and there is also less chance that it will get lost (physically, at least). Going paperless is also good for the environment.

Online submissions have benefits for instructors as well, which include:

- Being able to provide higher quality, more consistent feedback in less time.
- Having a time stamp to confirm when a student's assignment was turned in.
- Having the capability to check for plagiarism automatically.

Most of the concerns that students and instructors voice about online submissions are related to technical difficulties during the upload process, changes in document format, the inability to resubmit a document if an error is discovered after the fact, unreliable Internet connections, and a personal dislike of technology in general. Ultimately, it is up to your instructor to decide whether the advantages of online submission outweigh the disadvantages.

Instructors have various options for providing feedback in your electronic documents. One option is to insert comments or mark up text using the Comments and/or Track Changes features in Word (see pp. 199–201 in Appendix J). A second option that applies specifically to PDFs is to open the PDF in Adobe Acrobat Reader. In this program, text can be highlighted and comments can be added on “sticky notes.” A third option for providing feedback can be used on either Word documents or PDFs uploaded to Turnitin. In Turnitin Classic, instructors can highlight text on the paper, click the **Comment** button on the side panel, and then type a comment (Figure 5.1, item ①). If this turns out to be a frequently made comment, it can be saved as a GradelMark and reused on the current paper or on other students' papers. The title of the GradelMark is limited to 40 characters, but there is plenty of room to add detailed explanations in the context box. The next time this comment is applicable, instructors simply drag the GradelMark off the side panel and drop it onto the student's paper (Figure 5.1, item ②). Additional comments can be added to existing GradelMarks; these additional comments are only displayed in that particular comment in that particular paper. However, universal edits to existing GradelMarks will be applied to all papers in which that GradelMark was used. Two other features that instructors will appreciate are

- GradelMarks can be saved in sets customized for individual assignments (Figure 5.1, item ③) and
- GradelMark sets can be shared, which allows grading to be more consistent across multiple lab sections.

Students are able to see their instructor's comments by clicking the assignment link to open their paper, clicking the large GradelMark but-

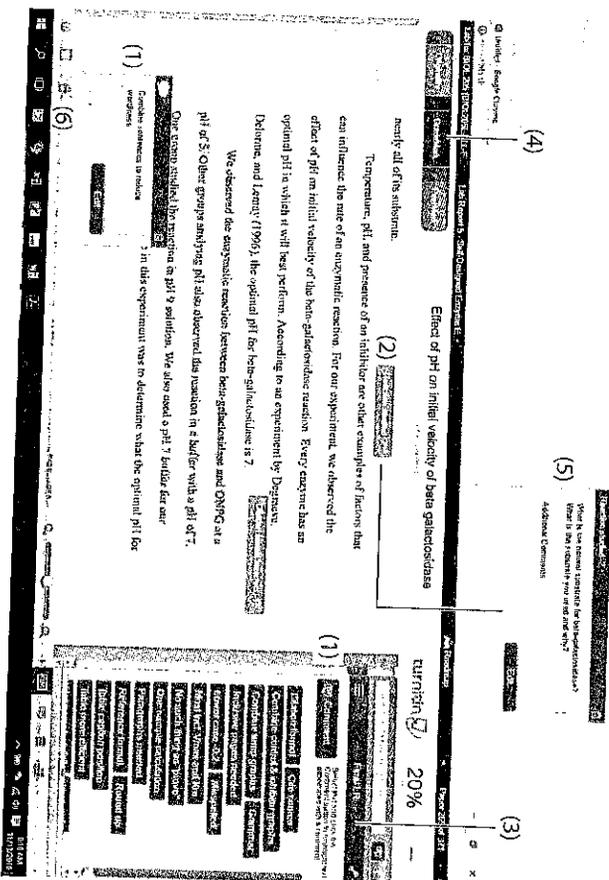


Figure 5.1 Comments and GradelMarks in Turnitin make it possible to provide consistent and detailed feedback on assignments. (1) After highlighting text, click **Comment** on the side panel to insert a comment that will only be reused in all assignments. (2) GradelMarks are organized into sets that can be customized for individual assignments. (3) Students click the GradelMark button to see their instructor's comments. (4) Comments expand when the cursor is held over the comment. (5) Comments with comments can be downloaded as PDFs or printed for future reference.

ton in the top left corner of the screen (Figure 5.1, item ④), and then holding the cursor over each comment (Figure 5.1, item ⑤). The document along with all of the expanded comments can be downloaded as a PDF or printed out for future reference (Figure 5.1, item ⑥). In the new version of Turnitin called *Feedback Studio*, some of these functions have been improved. For a comparison of Turnitin Classic and Feedback Studio, see, for example, <https://www.youtube.com/watch?v=tIKjBzJlE2g>.

Biology Lab Report Checklist

TITLE (pp. 88–89)

- Descriptive and concise

AUTHORS

- Each author's first name is followed by his/her surname

ABSTRACT (pp. 87–88)

- Contains an introduction (background and objectives)
- Contains brief description of methods
- Contains results
- Contains conclusions

INTRODUCTION

- Starts with a general introduction to the topic (pp. 84–86)
- Contains a question or unresolved problem (pp. 84–86)
- Contains background information supported by in-text references (pp. 84–86)
- The selected references are directly relevant to the study (pp. 84–86).
- The in-text reference is formatted correctly according to the Name-Year, Citation-Sequence, or Citation-Name system (pp. 89–95).
- Information obtained from a reference is paraphrased. Direct quotations are not used (p. 90).
- The objectives of the study are clearly stated (pp. 84–86).

MATERIALS AND METHODS

- Contains all relevant information to enable a person with appropriate training to repeat the procedure (pp. 55–57).
- Routine procedures are not explained (pp. 57–58).
- Complete sentences and paragraphs are used—do not make a numbered list (p. 55).
- Past tense is used because these actions were done in the past and completed (p. 55).
- Passive voice is used to emphasize the action (active voice is allowed in some disciplines) (p. 55).

- Materials are not listed separately (p. 57).
- No preview is given of how the data will be graphed or tabulated (p. 58).

RESULTS

- Tables and figures are described in numerical order. The descriptive text for a table or figure immediately precedes that table or figure (see, for example, Figures 4.1, 4.3, and 4.4).
- Results are described in *past* tense (p. 79).
- Every sentence in the text is meaningful (p. 79 and pp. 108–110). Sentences such as *The results are shown in the figure below* are not meaningful.
- When a result is described, the figure showing that result is referenced, preferably in parentheses at the end of the sentence (p. 77–78).
- There are no tables and figures that are not described.
- The figure caption is positioned *below* the figure (p. 67). The table caption is positioned *above* the table (p. 63).
- Figure and table titles are informative and can be understood apart from the text (pp. 63–64 and 67–69).
- The results are not explained (p. 78).

DISCUSSION (pp. 81–84)

- The results are *briefly* restated.
- The results are explained and interpreted.
- Past tense is used when referring to your own results. Present tense is used to state scientific fact, which is information supported by experimental evidence and replicated by many different scientists. Results in journal articles are considered to be fact until other studies present evidence to the contrary (p. 54).
- The results are compared with those in journal articles.
- The results are related back to the original objectives stated in the Introduction.
- Any errors and inconsistencies may be pointed out.
- The significance of the results or their implications may be discussed in a broader context.

REFERENCES (pp. 89–101)

- The references consist mostly of journal articles, not secondary sources such as textbooks or websites.
- The references are formatted correctly and contain all the required information.
- All references listed in this section have been cited in the text. All in-text references have been included in this section.
- Reference management software saves time formatting references (pp. 24–30).

REVISION

- All questions from the laboratory exercise have been answered.
- Calculations and statistics have been double-checked (p. 105).
- The overall structure of the manuscript is correct (pp. 104–105).
- The overall structure of each section is correct (pp. 105–106).
- Figures and tables are formatted correctly (pp. 60–73).
- Sections, paragraphs, sentences, and words are coherent and meaningful (pp. 105–112).
- Individual words are used appropriately for the situation (pp. 112–120).
- All sentences are grammatically correct (pp. 121–124).
- All words are spelled correctly (p. 124).
- The correct punctuation marks are used (pp. 125–129).
- Abbreviations for unfamiliar terms are defined the first time they are used (p. 129).
- Standard abbreviations are used for units (Table 5.5, pp. 130–131).
- Numbers are formatted correctly and, when applicable, are followed by units (pp. 129–132).
- The format for section headings, lists, figures, tables, references, and typography is consistent (Table 5.6, pp. 132–133).

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Sample Student Laboratory Reports

A “Good” Sample Student Lab Report

The first laboratory report in this chapter was written by Lynne Waldman during her first year at Bucknell University, in an introductory course for biology majors. Lynne and her lab partners designed and carried out an original project in which they investigated the effect of a fungus on the growth of bean, pea, and corn plants.

Lynne’s report has many of the characteristics of a well-written scientific paper. When you look over her presentation, notice the style and tone of her writing, as well as the format of the paper. The comments and annotations in the margins alert you to important points to keep in mind when you write your laboratory report.

The presentation here has been typeset to fit this book and to accommodate the annotations. Your report should be formatted to fit standard 8.5 × 11 inch paper. Unless you are instructed otherwise, use a serif type (Times Roman is standard), double space, and leave at least 1 inch of margin all around.

For details on how to format documents in Microsoft Word, see “Formatting Documents” in Appendix 1.