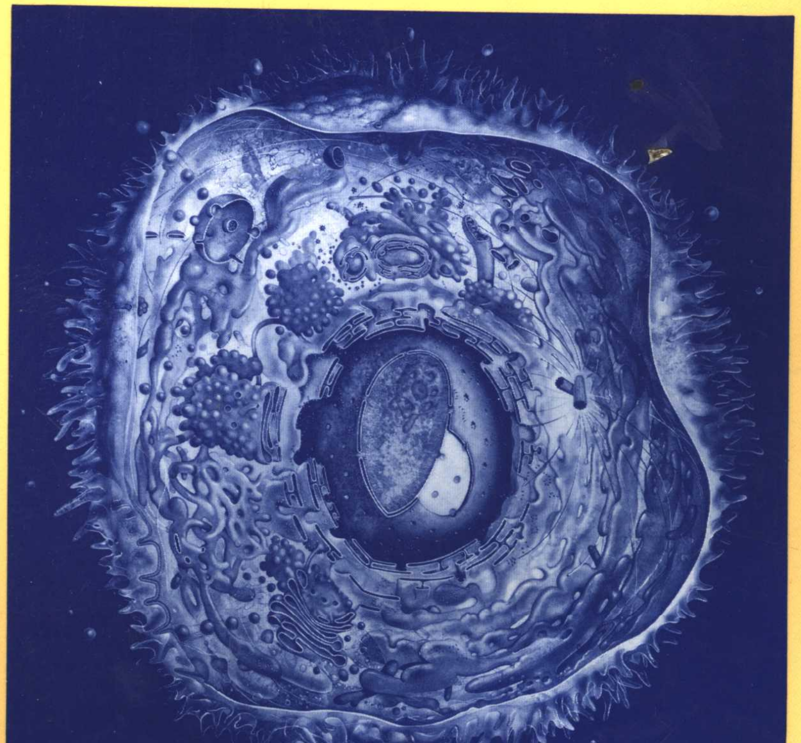
Laboratory Investigations in *Cell and Molecular Biology*

Revised Third Edition



Allyn Bregman

LABORATORY INVESTIGATIONS IN CELL AND MOLECULAR BIOLOGY

REVISED THIRD EDITION

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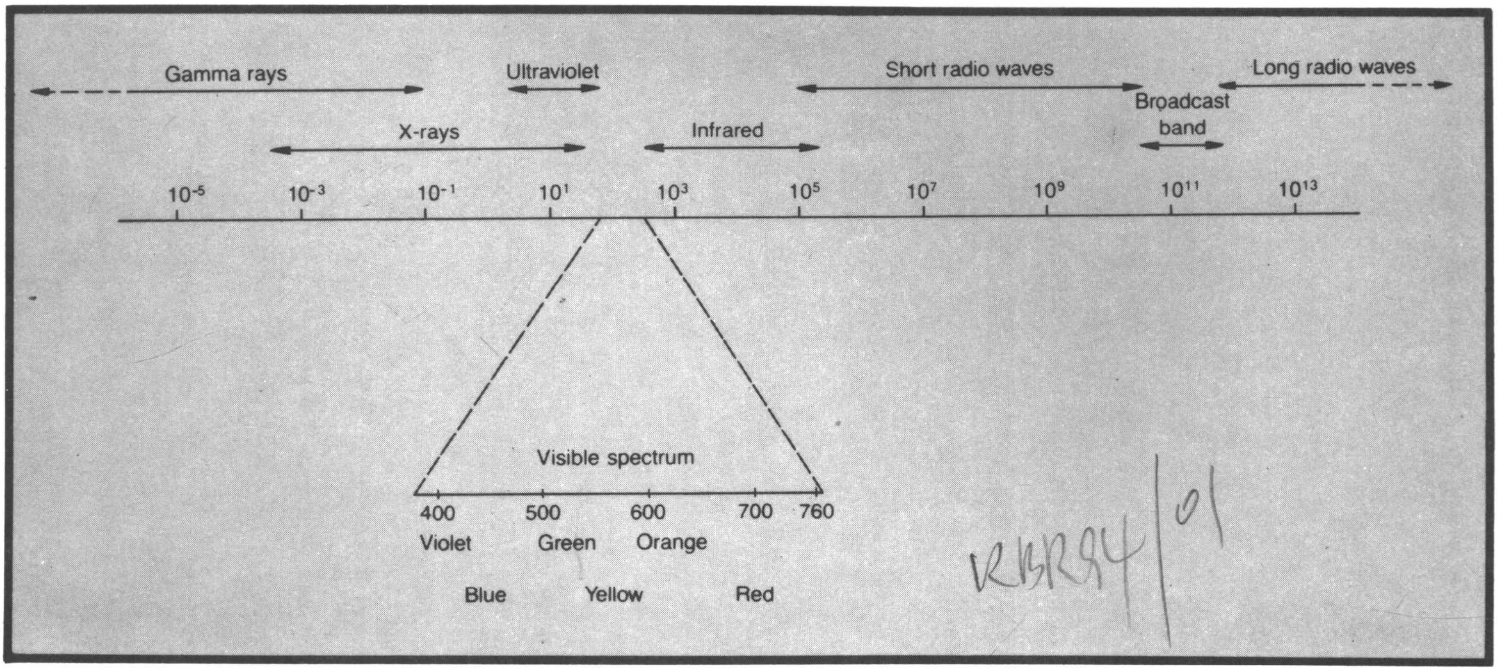
Meter (m)	Centimeter(s) (cm)	Millimeter(s) (mm)	Micrometer(s) (μm)	Nanometer(s) (nm)
1	10^{2}	10^{3}	10^{6}	10^{9}
10^{-2}	1	10	10^{4}	10^{7}
10^{-3}	10^{-1}	1	10^{3}	10^{6}
10^{-6}	10^{-4}	10^{-3}	1	10^{3}
10^{-9}	10^{-7}	10^{-6}	10^{-3}	1

1 inch = 2.54 cm = 25.4 mm
1 cm = 0.4 inch
1 mm = 0.04 inch
1 nm = 10 Angstroms (Å)

The Electromagnetic Spectrum. Wavelengths are in Nanometers (nm).



PREFACE TO THE REVISED THIRD EDITION

Laboratory Investigations in Cell and Molecular Biology is designed for the laboratory in mid-level cell biology courses. The 21 projects from the Third Edition are still in place, providing many options for one-semester courses. The topical sequence of the lab projects parallels the sequence found in most cell biology texts. The early projects deal with biochemistry and cytochemistry, the middle projects focus on organelles and their physiology, and the later projects explore more advanced molecular topics including restriction mapping strategies.

The projects have been designed to be as workable as possible. They can be carried out with a minimum of elaborate equipment and with a reasonable amount of preparation time. The materials are readily available and, wherever possible, botanical sources and lyophilized extracts have been chosen. The choice of materials was also guided by safety considerations. For example, DNA bands in electropherograms are stained with a conventional dye instead of with ethidium bromide. A complete *Instructor's Guide* follows the last project.

Each project opens with a clearly written *Introduction*, stating the objectives and explaining the theory that relates directly to the investigation. The procedural steps are detailed, permitting students to make acceptable preparations without the need for constant directions from the instructor. Each project concludes with *Observations and Questions* or *Exercises and Questions*, many of which involve critical thinking. Students are compelled to examine their findings as they pertain to the biological principles being investigated. Data sheets and graph paper are included to facilitate collection and analysis of the data. All bench work can be completed in a 3-hour lab session; a second lab session for observations is required for Projects 17 and 18.

The Revised Third Edition features an Introductory Chapter, entitled *Writing a Laboratory Report*. It acquaints students with the format, content, and writing style of a journal article. It also includes a short section on statistics, covering the mean, standard deviation, and standard error. The new chapter is designed to enable students to write up their results as a lab report. Lab reports provide an alternative to the *Exercises and Questions* and serve as another means of evaluating students in the laboratory. Just as important, students gain experience for a time when they may be writing a thesis or a journal article.

The following individuals deserve acknowledgment. My wife, Sybil, has provided invaluable editorial assistance for the Revised Third Edition. I am also grateful to Marian Provenzano and David Harris, the editors at John Wiley who encouraged development of the revision and saw the project through to completion. Also to be acknowledged are the thoughtful reviews of the Third Edition by R. Jane Hanas (University of Central Oklahoma), David A. Logan (Drexel University), and Robert W. Seagull (Hofstra University).

Allyn Bregman

INTRODUCTORY CHAPTER

WRITING A LABORATORY REPORT

A scientific investigation does not conclude with the final microscope observation or with the last absorbance reading from a spectrophotometer. Data must be tabulated, statistical tests performed, and electropherograms and photomicrographs evaluated to determine whether the findings support a particular hypothesis. If the study is sound and the results thought to be of interest, the researcher may present the findings at a conference or write them up in a report for publication. In this chapter, you will learn the appropriate format and writing style used throughout the scientific literature.

FORMAT OF A SCIENTIFIC ARTICLE

In writing up laboratory findings, you will use the format of a journal article. It is a user-friendly organization that makes it easy for the reader to locate background information, procedures, results, and conclusions. All scientific articles have a *title,* followed by an *Abstract.* An Abstract is a brief summary of the work. For the body of a scientific report, most journals require a format in which the text is divided into labeled sections: *Introduction, Materials and Methods, Results,* and *Discussion.* A list of *References* follows the Discussion. In some journals, such as *Science,* the text is organized as a single unit without labeled sections, yet the overall organization of the information in the text is similar. To become familiar with the content and writing style of a journal article, you should examine published works. A list of *Selected Journals in Cell and Molecular Biology* is provided at the end of the chapter.

The material in this chapter will guide you in writing a laboratory report in the format of a journal article. Included is useful information on developing a good title and Abstract, and on writing each of the four text sections. For each text section discussed in this chapter, there is an opening paragraph that describes the content of that section in a journal article. The remaining material in each section gives you guidance in writing that section for your lab report. There is also information on citing references in the text, as well as the proper format for listing them. The order in which the four text sections appear in a scientific paper is not necessarily the same as the sequence in which they are written. From experience, it has been found that the best sequence in which to write the text sections is: (1) Materials and Methods, (2) Results, (3) Discussion, and (4) Introduction.

Revision is such an important aspect of writing that a separate section is devoted to it (p.I-8). There is also a short section on basic statistics (p. I-9).

TITLE

The title is the first contact the reader has with the article or report, so the words must be carefully chosen. The reader should be able to determine from the title whether the subject is related to his or her own scientific interests. The title should be specific and accurately represent the content of the article.

An example will illustrate the principles for developing a good title. Consider possible titles for the *Experiment on Flagellar Function* (p. 185), which is in Project 14 (*Cell Motility*). In this experiment, the flagella are removed from a unicellular green alga. The deflagellated cells soon regenerate new flagella and resume their swimming. Both the flagellar regeneration and the return of motility are monitored microscopically. A major objective of the experiment is to ascertain the length of the flagella when cell motility returns. What would be an appropriate title for a lab report on this experiment? The title "Flagellar Length and Cell Motility" suggests a more extensive study of flagellar length and function than was done. "The Relationship between Flagellar Length and Cell Motility in *Chlamydomonas reinhardi*" is a better title because it includes the organism's scientific name, but it is still too general. An even better title is "The Return of Cell Motility in a Deflagellated Culture of *Chlamydomonas reinhardi*" because it effectively describes this particular experiment. In some cases, the title may also include the main conclusion.

In composing a title for your report, keep in mind that the first title you compose may not be the best one. Revisit it as you proceed through the writing and gain a deeper understanding of the significance of the work. As in all areas of writing, revision is a critical step.

ABSTRACT

The Abstract of a journal article is a brief and concise summary of the research. In a single paragraph, the Abstract presents the objectives of the study, the experimental design, the most important results, and the conclusions. It is a stand-alone statement that does not refer the reader to any portion of the article and does not contain technical details, tables, graphs, or references. Because of its brevity, many more individuals will read the Abstract than will read the body of the paper. Also, the Abstract of a published journal article is more accessible than the entire paper because it is published in literature indexes, such as *Biological Abstracts*. The best way to gain an understanding of what should be in an Abstract is to analyze them in a number of journal articles.

Although the Abstract is the first section of the report, it should not be drafted until all other sections have been written. You will summarize your report in the same manner as done for journal articles. For the Abstract and, indeed, for the entire report, you should use the past tense when referring to your findings.

INTRODUCTION

The Introduction section of a journal article gives the reader the background information needed to understand the subject and objectives of the research. It clearly states the questions that the research set out to answer or the hypothesis being tested, along with the experimental approach that was used. The Introduction also has the important role of putting the research in perspective. Through a summary of the pertinent literature, it relates the research to previous work in the field. Only the scientific literature that is directly related to the specific aims of the research is included.

Though only several paragraphs in length, the Introduction is a challenging section to write and should be drafted only after the sections on Materials and Methods, Results, and Discussion have been written. In writing the Introduction of a lab report, you should begin with the objectives of the investigation. Throughout the Introduction, you will be presenting the background information that bears on the subject. Depending on the subject, you may need to include information on the biological system, methodology, and the biological process or structure being studied. The appropriate amount and level of background information depend on your audience. Unless your instructor informs you otherwise, assume that you are writing for your peers, the students in your cell biology class.

As you present the relevant background information, you will refer to the scientific literature. The literature cited in the Introduction should be directly related to the main objectives of the investigation; a more complete exposition of the literature should be reserved for the Discussion section. For the Introduction section of a lab report, you may rely more upon textbooks and review articles than upon original journal articles. Whenever you present information from another source, you must include the literature citation in the text. For the correct form for a literature citation, refer to *Citing References in the Text* (p. I-8).

MATERIALS AND METHODS

The Materials and Methods section of a journal article informs the reader of the organism studied, the reagents and equipment used, and the procedures followed. When statistical analyses are performed, the names of the statistical tests are also included. The inclusion of procedural detail facilitates a comparison of the results with the findings in similar experiments and also permits others to repeat the experiment or extend the research.

The Materials and Methods section is generally the first section that is written. Because it contains mostly straightforward, descriptive information, drafting this section first is an easy way to "break the ice." For a lab report, you are usually required to write a complete Materials and Methods section. In this respect, your report will differ from a journal article, which often states that a lab protocol is the same as a procedure published elsewhere. Thus, for a lab report, it would be inadequate to write, "The procedure used was the same as that described in *Laboratory Investigations in Cell and Molecular Biology,* Revised 3rd ed. (Bregman, 1996)."

The writing style in the Materials and Methods section should be the same as in the other sections of the report. The procedure must be presented in a narrative style in the past tense, rather than as a list of steps in the imperative voice, as in a lab manual. Thus, a proper statement for a lab report would be, "The samples were centrifuged at low speed," and not, "Centrifuge the samples at low speed." As to how much procedural detail to give the reader, rely on common sense. Does the reader really need to know that the centrifuge tubes were balanced prior to each centrifugation? In general, such routine matters should be omitted or given little space.

RESULTS

The Results section of a journal article presents the data and observations that bear upon the objectives of the study. Results are presented in tables, figures, and an accompanying text, the narrative. The narrative describes the contents of the tables and figures as it highlights the most pertinent findings. When appropriate, statistical tests are also included in the Results section of a journal article.

Because the Results section contains the findings on which the entire report will be based, it is composed immediately after writing the Materials and Methods section. Before doing any writing, however, you need to assemble your data. In the cell biology laboratory, the data can take different forms. In studies that utilize microscopy, the data are usually qualitative in nature, consisting of a written description of cell types and their staining responses. Such descriptions are often accompanied by photomicrographs in journal articles. Microscopy data can also be quantitative, such as changes in the number and size of organelles or the time required for a certain physiological response to occur. Many investigations in the cell biology laboratory yield quantitative data, which are presented in tables and/or graphs. Other methodologies generate specialized presentations, such as electropherograms or densitometry tracings. Thus, the data presentations in the Results section vary considerably depending on the methodology.

After assembling the data, your next task is to analyze your findings and decide how they would best be presented in the Results. Which data should be presented in tables and graphs? Will there be other kinds of presentations? You also need to plan the most logical sequence in which to present your findings. That order is determined by the sequence in which the various questions and objectives are most logically addressed. For example, the data from control groups should be presented before the data from experimental groups.

For the projects in the manual where quantitative analyses are required, numerical data will have been entered on data sheets in the laboratory. *The data sheets are structured solely for ease of data collection and are not appropriate for inclusion in the Results section of your lab report.* For lab reports, you should convert data sheets into tables that are in keeping with the conventional format used in journal articles, as described below.

Tables. A table presents data in appropriately labeled rows and columns. Although tables are generally used for presenting numerical data, they can also be used for displaying qualitative results, such as the staining responses of different cell types. Whatever the form of the data, the table must be properly organized. The column headings across the top of the table indicate the various characteristics being studied, such as experimental groups, growth conditions, physiological attributes, or staining responses. The row headings along the left margin of the table indicate the sampling variables, such as time intervals, different cell types, or different species. An excellent discussion of tables and graphs can be found in *A Short Guide to Writing About Biology*, 2nd ed. (Pechenik, 1993).

As an example of how one proceeds from data collection to a final table, consider the data obtained in Project 15, *Flagellar Regeneration in* ***Chlamydomonas*** (p. 199). In this experiment, the flagella are removed from a unicellular green alga, after which the organisms are observed microscopically to monitor the growth of the new flagella in different culture media. At each time interval, the experimenter fixes a sample of cells for microscopic examination, measures flagellar length in 15 organisms, and enters the values on Data Sheet 15.1 (p. 205). These individual length measurements in ocular micrometer units constitute the *raw data.* While raw data are always saved as a record of the data collected in the laboratory, they are not appropriate for presentation to the reader. In this example, a table in the Results section would include only the *mean* lengths (in μm, *not* ocular micrometer units) because the mean is the best estimate of the length at each time interval. The mean and sampling variation are discussed in a short section on statistics on page I-9.

In the experiment, each team member collects data on flagellar length for a given culture condition. The data for each culture condition are entered on Data Sheet 15.2 (p. 207). Note the organization of the data sheet. The various culture conditions (Medium I, Colchicine, Cycloheximide) are column headings, while the sampling times are row headings. The data (mean flagellar length, in μm) are entered for each time interval in the body of the table. In this data sheet, the experimental conditions and the sampling variables have the same orientation that they will have in the final table. In other projects, you may have to reverse the column headings and row headings in the data sheet so that the table is appropriate for the final report.

As you prepare the various tables, it is helpful to make notes describing what is contained in each table and identifying significant findings. For example, your notes could include a statement about the tabular entry that indicates the flagellar length in each culture at the end of the experiment. Your notes will serve as a rough draft for the narrative that will be an integral part of the Results section.

Graphs. Graphs are used to reveal trends that would not be obvious in tabular form, such as the relationship between two variables. As an example, examine the graph in Figure 5.2 (p. 43). Depicted is a graph of absorbance readings that correspond to a set of concentrations of a particular substance. Graphs are structured with the dependent variable on the ordinate (y-axis) and the independent variable on the abscissa (x-axis). In Figure 5.2, the dependent variable is absorbance and the independent variable is concentration. Sometimes, a graph is required to obtain some critical value, such as an intercept or the slope.

Now, consider how the graph would be constructed in the experiment on flagellar regeneration (Project 15, Graph 15.1, p. 211). In this case, flagellar length is the dependent variable (y-axis) and time is the independent variable (x-axis). Each axis must be clearly labeled with the variable and units. In Graph 15.1, the y-axis would be labeled "Flagellar length (μm)," and the x-axis would be labeled "Time (min)." On Graph 15.1, there would be three plots, one for each culture condition. Where there are two or more plots on the same graph, different symbols are required, along with a key. Commonly used symbols are the open circle (○), the solid circle (●), the triangle (△), and the square (□).

Graphs should be drawn on quality graph paper that has heavier lines at uniform intervals, such as the graph paper provided with individual projects in this lab manual. How are data plotted? As a first step, you should plan the spread of numerical units on each axis. The increment used for each interval on the graph paper depends on the range of values for each variable. Try to use a large portion of each axis but enter "round" numbers at each interval. For example, it is preferable to use an increment of 0.10 μm instead of 0.09 μm, even though the latter would result in more of the axis being used.

When the appropriate units have been noted on the axes, the points can be plotted. Every data entry in the table becomes a single point on the graph paper. After the data points have been entered, you need to determine the best way to connect them. If all the points fall on a straight line, it is a simple matter to use a ruler to draw the line. This is the case in Figure 5.2 (p. 43). More commonly, the points will not all line up, and you will have to decide on the best-fit line or curve. You will have to decide whether there should be (1) a compromise straight line with some points evenly distributed above and below the line; (2) a smooth curve that closely connects the points; or (3) a combination of a straight line and a smooth curve. If the points suggest a smooth curve, you should use a French curve template to draw it. Regardless of the shape of the curve, it should not be drawn freehand. In some cases, it may be permissible to use a computer-generated best-fit line or curve.

In journal articles, you will find that only the graph is included when the same data could be presented in both a table and a graph. For the purposes of a lab report, however, you are expected to include both the table and the graph. The table is helpful in the lab report because it shows the actual values you obtained.

After you have had an opportunity to examine each graph, begin to make notes of the important features. In Project 15, for example, your notes could start with the course of normal flagellar regeneration. Then, the notes could go on to describe the trends for the experimental conditions. Look for observations that relate to the hypothesis and then begin writing appropriate text to draw the reader's attention to the pertinent data. Again, your notes on each table and graph will be a basis for developing the narrative.

Numbering and Labeling Tables and Figures. All tables and figures must be numbered and have a legend. If a lab report has two tables, they should be identified as "Table 1" and "Table 2," in the order that they are referred to in the narrative of the Results. Any presentation of data other than a table is labeled as a "figure." Thus, each graph is labeled as a figure, as is each photomicrograph and each electropherogram. If the Results section in your report contains two graphs, one electropherogram, and one photomicrograph, they would be identified as Figure 1, Figure 2, Figure 3, and Figure 4, numbered in the order that they are referred to in the narrative. Every table and figure must be referred to in the narrative of the Results section.

In addition to being numbered, every table and figure must have a legend. The legend begins with the title, which is a phrase describing the table or figure. The title should be concise but detailed enough to be self-explanatory. Sometimes, an additional statement is needed to inform the reader of an experimental condition that is critical to understanding the table or figure. The goal is for every table and figure to be self-contained, so that the reader can understand them without having to consult the text.

Narrative. The narrative is not a separate section within the Results section but commentary that is interspersed with the tables and figures. One way to begin writing the narrative is to expand upon the notes you have made on each table and figure. The narrative of the Results section informs the reader of the content of each table and figure and points out the important results. If your findings allow a question to be answered, the specific conclusion should be clearly stated. Furthermore, the narrative should direct the reader to the data that support your conclusion. Thus, the reader may be directed to specific entries in a table, to a particular graph, or to certain features of an electropherogram. Any negative results that are important should also be mentioned. The total length required for the explanatory material need be only several paragraphs, but an adequate narrative must be included.

Consider statements that could be appropriate for the experiment on flagellar regeneration. The data might permit the researcher to comment on the culture in which flagellar regeneration was observed to be most complete. Thus, there could be a sentence that refers the reader to the table and the entry for the greatest flagellar length at the last sampling time. In this way, the reader's attention is focused on the pertinent data. Similarly, if you wanted to highlight the differences in growth rate among the cultures, you would refer the reader to the figure with the flagellar growth curves. You might then focus on the curve with the greatest slope during the first 20 minutes.

The final narrative should contain all important findings; however, the narrative should not contain any interpretations of the findings. Interpretations should be reserved for the Discussion.

DISCUSSION

It is in the Discussion section of a journal article that the researcher interprets the results, especially as they relate to the question or hypothesis that the research was designed to examine. The researcher also compares the results to findings previously reported in the literature, generally in journal articles. Any differences from previous work are pointed out and, if possible, explained. The Discussion section of a scientific article often concludes with the implications of the research and suggestions for future studies.

The Discussion is drafted only after the Results section has been written. Proceeding from data to interpretations is a challenge, which makes the Discussion perhaps the most exciting section to write. In your lab report, the emphasis of the Discussion should be on the objectives of the investigation. How well did your findings answer the questions posed? What are reasonable interpretations of the results? The *Exercises and Questions* section at the end of each project touches upon areas for interpretation.

In the experiment on flagellar regeneration, for example, the main findings are the observed differences in flagellar growth in the cultures with colchicine and cycloheximide, compared to the observations in the standard culture medium. There are various issues to be considered in the Discussion. Are the results consistent with the known biological effects of the two chemicals? How might the observations be interpreted in light of the proposed mechanism of microtubule assembly in flagella? To address such questions, it is necessary to discuss the relevant literature. The use of references and the proper way to include them in the text are discussed in *Citing References in the Text* (p. I-8). In addition to the main findings, there may be other interesting observations that you would like to discuss. Such peripheral topics should certainly be included, but only after the central questions of the investigation have been discussed.

In the cell biology laboratory, you are likely to be repeating previous research that has been published in a journal article. You need to consider how your findings compare to the previous work. Because the original experimental conditions are unlikely to be duplicated exactly, there may be some interesting comparisons to be drawn and differences to explain.

It may turn out that some of your results are unexpected. Similarly, there may be a single data set that is inconsistent with the bulk of the data or the general trend. It is in the Discussion that unexpected results and experimental error are addressed. For unexpected results, you need to give thought to what condition in the experiment could have caused them. Be careful to include in the Discussion only those sources of error that are realistic.

The Discussion section often concludes by proposing lines for future research based on the present study. The suggestions could include an entirely new approach to the problem or a follow-up experiment. For example, in the Discussion section of a lab report on flagellar regeneration, there could be suggestions for the use of some other chemical with known biological effects that would further elucidate the process.

What about the writing style of the Discussion section? As in other sections of the paper, the past tense is used when referring to your findings. Because you will be speculating about implications of the results, some of your statements may need to be stated cautiously. Caution is expressed by the verbs "suggest," "appear," and "seem." There is really only one way to achieve clarity in the report and that is to revise the writing several times. The process of revision is described on page I-8.

REFERENCES

The References section of a journal article is a list of all cited references. In most journals, the references are listed alphabetically by the last name of the first or sole author. Each listing must be complete, including the names of all authors. If there are two articles by the same author, the item with the earlier publication date is listed first. Each scientific journal has its own requirements for how the information in each type of reference should be organized. While there is no universally accepted format for each type of publication, the formats used in the examples that follow can be used in a lab report.

Listing a Journal Article. The information to be included for a cited journal article in the References section is illustrated by the following two listings. The sequence of information is: author(s) (last name, initials), year of publication, title of the article, title of the journal (italicized or underlined), volume, and inclusive page numbers. Standard abbreviations are used for journal titles of more than one word. Abbreviations can be found in *Periodical Title Abbreviations: By Title,* Vol. 2.

Pardue, M. L. and Gall, J. G. 1970 Chromosomal localization of mouse satellite DNA. *Science* 168:1356–1358.

Sanger, F., Coulson, A. R., Hong, G. F., Hill, D. F., and Petersen, G. B. 1982. Nucleotide sequence of bacteriophage λ DNA. *J. Mol. Biol.* 162:729–773.

Listing a Book. The sequence of information for a cited book is: author(s), year of publication, title (italicized or underlined), volume number (if any), edition (after the lst), pages cited, publisher, and location.

Pearse, A. G. E. 1985. *Histochemistry, Theoretical and Applied,* Vol. 2, 4th ed., pp. 686–692, 850–852. Churchill Livingstone, Edinburgh.

Listing an Article or Chapter in a Book. For an article or chapter within a book, such as an edited monograph or a volume in a series, the sequence of information is: author(s) of the article/chapter, year of publication, title of the article/chapter, title of the book or series (preceded by "In"), volume, editor(s), inclusive page numbers of the article/chapter, publisher, and location.

Izawa, S. and Good, N. E. 1972. Inhibition of photosynthetic electron transport and photophosphorylation. In *Methods in Enzymology,* Vol. 24, San Pietro, A., ed., pp. 355–377. Academic Press, New York.

Citing References in the Text. References are included in a scientific article to indicate that statements, ideas, and data are derived from other sources. Inclusion of references allows the reader to go to the source in order to learn more about the subject or to verify the accuracy of the statement associated with the citation. Any statement that is not your own must have a reference. When in doubt about whether a reference is needed, it is best to include it.

Literature sources can include textbooks, monographs, review articles, and journal articles. Textbooks, monographs, and review articles are appropriate for information on underlying biological concepts, whereas journal articles are the primary source of information on specific research findings and procedures. Whether you are referring to a book or an article, be sure that you have read the reference that you cite.

For every statement that requires a reference, the citation must be included both in the text and in the References section. In the text, the statement requiring the reference is followed immediately by the author(s) and publication date, in parentheses: "In the mouse, satellite DNA is located at the centromeric region of every chromosome except the Y (Pardue and Gall, 1970)." Sometimes, the author's name is part of the narrative. In that case, the publication date, in parentheses, follows the name(s): "Sanger *et al.* (1972) have determined the complete nucleotide sequence of phage lambda DNA." The phrase *et al.*, which means "and others," is used in the text citation when there are more than two authors. The names of all the authors are included in the journal listing under References.

REVISION

Very few individuals can compose a perfectly clear, error-free first draft of any significant written work. Most authors have to revise several times to achieve a final draft. As you reread your first draft of the lab report, you will immediately notice some areas that can be improved. However, there is really no substitute for the objectivity that comes only when you have *not* looked at the paper for a while. Accordingly, prepare the first draft as early as possible so that you will have the time to let the paper sit before reviewing it again.

There are many issues to be considered when reviewing your lab report. In your first review of the report, you should focus on content. Has everything that is supposed to be in each section been included? As you read each section, watch for material that would be more appropriate for another section. In checking for content, make sure that all the required tables and figures have been included in the Results. Do all the tables and figures have legends and have all been referred to in the narrative?

You also need to assess the literature sources for completeness. Have you incorporated the literature where it is needed? Is there adequate documentation wherever you have presented background information? Be sure that citations are included for all statements that require them. Check, too, that the complete citation is included in the References section.

In your next reading of the lab report, concentrate on clarity of the text. Your explanations should be clear enough so that the reader can follow your arguments and reasoning. When presenting complex ideas, you should always expand upon your initial statement. You also need to present the ideas in a logical sequence. Are the paragraphs in the best order or should some be moved to improve the sequence? For ease of comprehension, should some of the very long paragraphs be divided?

You should also review the lab report for proper writing style. Make sure you have used the correct tense for verbs. The present tense is used for generalizations and accepted facts, while the past tense is used when referring to your findings. The past tense shows that you are limiting your conclusions to your own investigation. Caution is also expressed by hedging verbs, such as "suggest" and "may." They are useful in the report, but be careful not to include more than one such word in the same statement. Check, too, that pronouns are properly used; if it is not clear what an "it" or "they" refers to, rewrite the sentence or use the actual noun instead.

How should numbers be written in text sections of the paper? The numbers zero through nine should be written out when they occur in a line of text, while numerals should be used for larger numbers. There are exceptions, however. Numerals should always be used for percentages, decimals, and commonly used units: 2%, 6 ml, 4° C, 8 μm.

Make sure that your writing is concise. There are many wordy phrases that can be replaced by shorter expressions. For example, "pale blue in color" can be replaced by "pale blue," and "for the purpose of measuring" has the same meaning as "to measure." Think about every word used in your report; each word should be carefully chosen so as to convey exactly the meaning you have in mind. Each sentence should be necessary and meaningful. The final report should be focused, not rambling. An excellent source on the revision process and on writing style can be found in the *Council of Biology Editors Style Manual,* 5th ed. (CBE Style Manual Committee, 1983).

Word processors and computers are invaluable in the revision process and, if at all possible, should be used to write your lab report. As you review what you have written, you will no doubt make a lot of changes, such as moving sections, deleting sentences, and inserting new text. Word processing allows such cut-and-paste changes to be made with a few keystrokes. Many word processors can also assist the writer by picking up spelling errors and even obvious grammatical mistakes. If your software program has such capabilities, be sure to use them. Everyone prefers reading a report that is free of spelling and grammatical errors.

If you have proceeded in a deliberate and careful manner from data collection through revision, you will surely have a finished product that you can be proud to share with your colleagues.

STATISTICS: THE MEAN, STANDARD DEVIATION, AND STANDARD ERROR

Statistics deals with the relationship between samples and the populations from which they are drawn. Consider, for example, measurements of nuclear size in a particular tissue. The investigator measures nuclear diameter (to the nearest μm) in a sample of 10 cells and obtains the following data: 7, 6, 4, 8, 4, 7, 6, 5, 6, 7. As is usually the case, it is not possible to measure a characteristic in all members of a population. Nor is it necessary because statistical methods permit an analysis of characteristics of the population just from the sample data.

The best known sample statistic is the mean. The *sample mean* ($\overline{X}$) is defined as the sum of the measurements, each referred to as a *variate* (X), divided by the number of items in the sample (N). In symbols, the relationship is

$$\overline{X} = \frac{\Sigma X}{N}$$

The sample mean is an estimate of the *population mean.*

A commonly used statistic that indicates the dispersion of the variate is the *standard deviation* (SD). The formula used to obtain the standard deviation with a calculator is

$$\text{SD} = \sqrt{\frac{\Sigma X^2 - (\Sigma X)^2/N}{N - 1}}$$

In the numerator, the first term is the sum of X squared, and the second term is the square of the sum of X divided by N. The denominator is the sample size minus one. The units for SD are the same as for the variate. The standard deviation, SD, is a measure of the dispersion of the variate in the sample and is also an estimate of the *standard deviation of the population.*

In our study of nuclear size, and in most studies, we are more interested in the dispersion of means than in the dispersion of the variate. Specifically, we would like to know how much variation would occur among means if repeated samples of size N had been drawn from the original population. The required statistic is the *standard error of the mean,* commonly referred to as the *standard error* (SE). It is calculated from the expression

$$\text{SE} = \frac{\text{SD}}{\sqrt{N}}$$

which is simply the standard deviation divided by the square root of the sample size. Again, the units are the same as for the variate. Shown below are the calculations for the mean ($\overline{X}$), standard deviation (SD), and standard error (SE) for the 10 nuclear diameters.

$$\overline{X} = 60/10 = 6.0\ \mu\text{m}$$

$$\text{SD} = \sqrt{\frac{376 - (60)^2/10}{10 - 1}} = 1.33\ \mu\text{m}$$

$$\text{SE} = 1.33/\sqrt{10} = 0.42\ \mu\text{m}$$

It is common practice to include the standard error along with the sample mean, in the form "Mean ± SE." Whenever the standard error is given, the sample size should be noted as well. Thus, in the numerical example above, the mean can be written as 6.0 ± 0.42 μm (N = 10). The standard error is a very useful statistic because it can be used to determine a *confidence interval.* A confidence interval for the sample mean is a range of values that is likely (how likely depends on the probability chosen) to include the true value of the population mean. Additional information on the standard error and confidence intervals can be found in any text on statistics or biostatistics, such as *Introduction to Biostatistics,* 2nd ed. (Sokal and Rohlf, 1987).

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