SCIENTIFIC WRITING FOR MICROBIOLOGY MAJORS

The main purpose of most scientific writing is to inform and educate other people about research that has been performed. A scientific report should explain clearly how the research was performed and what results were observed. "Good science" must be repeatable – other scientists should be able to repeat the experiment in order to see if they come up with the same results or not. And lastly, an argument or opinion might be proposed based on the results obtained.

Typically students are introduced to scientific experimenting by way of the hypothesis model. Researchers formulate a hypothesis that they would like to test and design an experiment that will either prove or disprove the hypothesis. Scientific writing is a means of presenting the results of a particular experiment – what hypothesis was tested, how it was tested, what the results of the testing were, and what the results prove or disprove.

Scientific writing should be:

- Clear
- Objective
- Accurate
- Concise

As a researcher, it is essential to keep in mind that you are trying to persuade your audience of the importance and validity of your experiment. After all, it is only after a hypothesis has been proven or disproved numerous times by many different researchers that the information gained will become part of the scientific dogma. This is only possible if experimental results are written up in such a way that the information is comprehensible and convincing.

GENERAL STYLE

Voice

Most scientific writing is written in an objective manner, with little drama or flair. Typically the results are being showcased, not the writing. The purpose of scientific writing is not to entertain; the purpose is to inform. The writing should be simple and easy to understand. The style of the writing itself is relatively formal - the use of slang and the overuse of contractions should be avoided.

Because science and scientific research is supposed to be presented objectively, scientific writing has traditionally been written in a passive voice. The pronouns "I," "We," and "They" were typically not used. For example, instead of writing "I used MacConkey agar to isolate the bacterium *Escherichia coli,*" it is more customary to write, "MacConkey agar was used to isolate the bacterium *Escherichia coli*." This is still the rule for Material and Methods, but recently the convention is changing and the active voice is more commonly used in journal articles today (Refer to Day, 1994).

Verb Tense

Most of scientific writing is in the past tense, although there are exceptions. Everything that the researcher has performed is described in past tense. This includes the summary of the experiment performed (the abstract), description of the materials and methods used to perform the

experiment, and the results obtained from the experiment. The present tense is reserved for the researcher's conclusions about the experimental results, conclusions of previous researchers, and any facts that are generally accepted by the scientific field. These are found in the introduction and parts of the discussion.

Although most writing guides stipulate that the tense should be coordinated within a sentence or paragraph, there are exceptions. According to the American Society for Microbiology (ASM) 2001 Instructions to Authors (found in the beginning of every journal of ASM), there are some instances where it is acceptable to vary the tense in a single sentence. The examples given by ASM as acceptable include:

> "White (3) demonstrat*ed* that XYZ cells *grow* at pH 6.8,"
>
> "Figure 2 *shows* that ABC cells *failed* to grow at room temperature,"
>
> "Air was remov*ed* from the chamber and the mice died, which *proves* that mice require air,"
>
> "The values for the ABC cells *are* statistically significant, indicating that the drug inhibit*ed*…"

Microbial Nomenclature

The rules governing the naming of prokaryotes are established by the International Committee on Systematics of Prokaryotes (ICSP). Binary names consisting of genus and a specific epithet (commonly referred to as species) are used for most microorganisms (the exception to this is the viruses, see information below). A species is a binary combination consisting of a genus followed by a specific epithet. In other words, you would never refer to the species without the accompanying genus. The genus name is capitalized and the species is lower case. The names should be italicized or underlined in text. Once the complete name of a microorganism has been written out once, the genus name can be abbreviated to just the capital letter provided there is no confusion with other genera. Example: *Staphylococcus aureus* can be written as *S. aureus* the second time, as long as no other genera in the paper start with the letter "S." However, the ICSP recommends that the entire name be spelled out again in the summary of any publication.

The designation "sp." after a genus refers to a single unnamed species, while the designation "spp." after a genus refers to more than one unnamed species. Example: *Salmonella* spp. refers to more than one species of *Salmonella*. In lists that contain a series of species all belonging to the same genus, it is acceptable to name the genus only once, even if the other species have not been mentioned previously. Example: *Clostridium tetani, C. botulinum, C. perfringens*....

Often bacteria are divided into subspecies, which are indicated by "infrasubspecific subdivisions" such as: biovar (usual abbreviation: bv.), chemoform, chemovar, cultivar (usual abbreviation: cv.), *forma specialis* (abbreviation: f. sp.), morphovar, pathovar (usual abbreviation: pv.), phagovar, phase, serovar, and state. This is placed, in roman text, before an additional italicized name. Example: *Rhizobium leguminosarum* biovar *viciae*. The ICSP does not have rules covering taxa below subspecies, such as for a strain designation, which should

follow after the genus and species and may be a combination of letters and numbers. Example: *Escherichia coli* O157:H7, where O157:H7 designates the particular antigenic strain of *E. coli* that is being used.

The rules governing the naming of viruses are established by the International Committee on Taxonomy of Viruses (ICTV). The controversy surrounding the naming of viruses is ongoing and unresolved. Viruses are also given a genus and a species, and frequently a strain categorization. However, there are many difficulties in establishing viral species and viral strains. Because of this, the ICTV currently requires that the English common name, rather than a Latinized binomial term, be used to designate a viral species. For example, HIV is classified as family Retroviridae, genus *Lentivirus* (note the italics), and species Human Immunodeficiency Virus. The virus is then commonly referred to by its species name.

Genetic Nomenclature

(The following information was copied from a website produced by Susan Payne, Associate Professor, Department of Biology, University of Texas at Arlington. The website address is: http://www.uta.edu/biology/payne/3445/mutants_mutations.htm).

Gene names are designated with 3 letters that form a mnemonic descriptive of gene function: *his* for histidine biosynthesis. If more than one gene product contributes to a specific function then capital letters are used. For example, 8 genes are involved in histidine biosynthesis *hisABCDEFGHI.*

An auxotroph that needs histidine to grow would be a *his* mutant. Thus a *his* mutant may have mutations in *hisA, hisB, hisC* etc. The phenotype is His-, or simply His, in comparison to the wild-type organism which would be His+. Note that the phenotype designation is not italicized. The genotype denotes the actual mutation: for example *hisA* (note that genotype designations are frequently given before the function of the gene product is known). Alleles are different forms of a gene, therefore different mutations in a gene are alleles. Alleles are designated with numbers. Thus *hisG251* is different than *hisG252*. Deletions are noted with the Greek capital letter Delta (Δ). A Δ(*hisG-hisD*) is a mutation encompassing the *hisG* and *hisD* genes.

Insertions are designated with **::** Insertions are frequently caused by transposons or phage. Thus a particular Tn*10* insertion in the *hisG* gene might be *hisG9425*::Tn*10*. That means that there is a Tn*10* insertion into *hisG*.

Antibiotic sensitivity is referred to as s (sensitive) versus r (resistant). Amp^r denotes an ampicillin resistant strain.

ORGANIZATION AND FORMAT

Basic Outline

Scientific writing can be in the form of a laboratory report, a thesis, a journal article, or some other written communication used to disseminate the results of scientific research. The exact format required depends upon the type of written communication and often will vary from source to source.

Preparation of a Laboratory Report

A lab report differs from a paper in that it has defined sections. The sections required vary from laboratory to laboratory but the standard outline for most lab reports in the biological science include: title, your name, purpose of the experiment, methods, results, discussion and conclusion, references. Some lab reports may include a section of questions that must be answered concerning the experiment. Most laboratory courses will require that data be immediately written into a lab notebook in pen. Some labs will require you to attach these data pages to your report. Normally a lab report should be typed, spell checked and proofread before being submitted.

When writing a thesis, article for publication, or a report to turn into your supervisor, your first draft will be reviewed by your mentor and/or co-workers and then undergo revision. No matter how good a writer is, most reports require some revision. It is best to write your first draft and then let it sit for a few days before you read it the next time. Many times you are too "close" to the material after the first writing to see obvious errors. (This has definitely been true of this document!)

Sections of a Laboratory Report

Title: The title should be concise and specific and tell the reader what you did

Purpose: Most lab reports do not include a formal introduction and instead substitute a purpose. The purpose of the experiment should be stated in one or two sentences. You should know the purpose of the experiment before you start.

Methods: Most lab reports do not include all the details a journal article requires. Normally the procedure can be listed and referenced to the appropriate laboratory manual pages. If modifications have been made to the methods in the lab manual, these need to be clearly described.

Results: All data and observations should be included in the lab book; however, what you think should have happened or the methods section are not included. Types of results may include:

1. Measurements. Report measurements using standard metric units. Any time a number is presented, it must have units. Abbreviations of units are used without a following period. Use the prefixes m, μ, n, and p for 10^{-3}, 10^{-6}, 10^{-9}, and 10^{-12}, respectively. Numbers should be written as numerals when they are greater than ten or when they are associated with measurements; for example, 8 mm or 20 g. In a list of objects including both numbers over and under ten, all numbers may be expressed as numerals. Example: 17 bacteria, 2 yeast, and 1 protozoan. If a number starts a sentence spell out the number, do not use a numeral. Example: ten mannitol salt agar plates were streaked…

2. Calculations. The equation should be indicated. In a lab report, even if you use a calculator, you must set up the problem.

3. Tables. Number each table and provide a title and legend that contains all the information needed to interpret the data. The reader should be able to understand the

content without the text. The title should be located at the top of the table. Columns and rows should be labeled clearly. All notes should be placed below tables. Any abbreviations, units, calculations, or statistics used should be described in headers or footnotes (see Table 1 for an example). Symbols such as **#, *, !**; and superscripts such as **[1]** and **[2]** can be used to identify these footnotes. Use bold type to make these obvious.

4. Figures. Figures include graphs, photographs, drawings, diagrams, maps, and all other illustrations. All figures should be numbered and have a title and legend that contains all the information needed to interpret the data. The reader should be able to understand the content without the text. Figures should be labeled at the bottom. For a graph, units are specified on the abscissa and ordinate. If the photograph is of an object under the microscope, the total magnification should be indicated. Photographs of gel electrophoresis data should include a number on each lane, and the legend (or the figure itself) should indicate the contents of each lane.

5. Plate counts. Include results for all dilutions, even if they are too numerous to count (TNTC) or 0. You should indicate the type of medium plated and temperature of incubation. See Table 1.

Table 1. Results of viable cell count of diluted *Escherichia coli* grown at 37^{o}C in nutrient broth (1 ml plated).

Dilution of culture	Plate counts, colony forming units (CFU)/ml*
10^{-2}	TNTC (>250), TNTC
10^{-3}	249, 235
10^{-4}	35, 23
10^{-5}	3, 5

*In this example, only 249, 235 and 35 are significant counts. These data are averaged: $249/10^{-3} + 235/10^{-3} + 35/10^{-4}$ **or** $2.5 \times 10^{5} + 2.4 \times 10^{5} + 3.5 \times 10^{5}/3$ $= 2.8 \times 10^{5}$ CFU/ml

The text should refer to each table and figure and they should appear after, but close to, text that refers to them, (i.e., at the end of a paragraph or section). Alternatively, tables and figures may be placed at the end of the paper. Tables and figures are numbered independently of each other, and they are assigned numbers in the order they are mentioned in the text. The in-text reference to a table or figure should not repeat the caption (e.g. 'table 1 shows "Title on table" '). Instead, it should draw attention to key features (e.g. "Table 1 shows that the number of bacteria in the culture increased markedly between hours 1 and 4.").

Discussion/Conclusion: The discussion section interprets the meaning of the results and draws conclusions from the data that have been presented. The authors should show how their observations relate to each other to form a cohesive story. If data can be interpreted in more than one way, all possibilities should be mentioned and the authors should indicate which alternative they think is correct and why. Results should be discussed even if they are unexpected or negative. For example, the presence of unexpected bands on agarose gels should be explained.

This section should also address any discrepancies between these results and other papers. Material obtained from another source should be referenced.
The meaning of your results should be summarized in two to three sentences at the end of the section. This includes the potential implications of the research, and possibilities for future research that would contribute more to the field. In lab reports, experiments do not always work. This section allows the researcher to explain what might have gone wrong with an experiment.

References: The reference section gives complete details about sources that were cited, in any section of the text. A "Bibliography," on the other hand, refers to a list of materials used to obtain background knowledge on a subject. There are several standard styles for listing references. Depending on what type of scientific writing you are doing, you may be directed to follow a particular format. If so, follow the format that has been specified exactly. When references are cited, either the reference number or the author's last name and the publication year are used. Example: "Some strains of *E. coli* can grow in orange juice (1)…" or "Some strains of *E. coli* can grow in orange juice (Brown, 1999)…." In this class, we will use the reference style of the American Society for Microbiology Journals. When **references** are **cited within the paper**, only the number is used. References are then numbered in alphabetical order. No reference should be included that is not cited in the paper. Remember that ALL information within the report that is not your original work or idea should be referenced. Statements by other authors are usually paraphrased or summarized – direct quotations are rare in scientific writing.

The following examples are from the directions to authors found in the front of all American Society for Microbiology (ASM) journals:

(i) References cited in text. The References section must include all journal articles (both print and online), books and book chapters (both print and online), patents, theses and dissertations, and published conference proceedings (not abstracts; see below), as well as in-press journal articles, book chapters, and books (publication title must be given). All listed references **must** be cited in the text. Arrange the citations in **alphabetical order** (letter-by-letter, ignoring spaces and punctuation) by first author and **number consecutively.** Abbreviate journal names according to *BIOSIS Serial Sources* (BIOSIS, Philadelphia, Pa., 2000). Cite each listed reference by number in the text.

Follow the styles shown in the examples below:

1. **Arendsen, A. F., M. Q. Solimar, and S. W. Ragsdale.** 1999. Nitrate-dependent regulation of acetate biosynthesis and nitrate respiration by *Clostridium thermoaceticum*. J. Bacteriol. **181:**1489–1495.
2. **Cox, C. S., B. R. Brown, and J. C. Smith.** J. Gen. Genet. in press.* *{Article title is optional; journal title is mandatory.}*
3. **De Ley, J., M. Gillis, and J. Swings.** 1984. Family VI. *Acetobacteraceae* Gillis and De Ley 1980, 23 *VP*, p. 267–278. *In* N. R. Krieg and J. G. Holt (ed.), Bergey's manual of systematic bacteriology, vol. 1. Williams & Wilkins, Baltimore, Md.
4. **Dunne, W. M., Jr., F. S. Nolte, and M. L. Wilson.** 1997. Cumitech 1B, Blood cultures III. Coordinating ed., J. A. Hindler. American Society for Microbiology, Washington, D.C.

5. **Fitzgerald, G., and D. Shaw.** *In* A. E. Waters (ed.), Clinical microbiology, in press. EFH Publishing Co., Boston, Mass.* *{Chapter title is optional.}*
6. **Gershon, A. A., P. LaRussa, and S. P. Steinberg.** 1999. Varicella-zoster virus, p. 900–911. *In* P. R. Murray, E. J. Baron, M. A. Pfaller, F. C. Tenover, and R. H. Yolken (ed.), Manual of clinical microbiology, 7th ed. American Society for Microbiology, Washington, D.C.
7. **Green, P. N., D. Hood, and C. S. Dow.** 1984. Taxonomic status of some methylotrophic bacteria, p. 251–254. *In* R. L. Crawford and R. S. Hanson (ed.), Microbial growth on C1 compounds. Proceedings of the 4th International Symposium. American Society for Microbiology, Washington, D.C.
8. **Odell, J. C.** April 1970. Process for batch culturing. U.S. patent 484,363,770. *{Include the name of the patented item/process if possible.}*
9. **O'Malley, D. R.** 1998. Ph.D. thesis. University of California, Los Angeles. *{Title is optional.}*
10. **van der Zeiss, L., and V. B. Danziger.** 1999. History of clinical microbiology. Clin. Microbiol. **100:**123– 234. [Online.] *{For online versions of print journals.}*
11. **Zellnitz, F., and P. M. Foley.** 2 October 1998, posting *{or* revision*}* date. History of virology. Am. Virol. J. **1:**30–50. [Online.] *{For online-only journals; page numbers may not be available.}*

* A reference to an in-press ASM publication should state the control number (e.g., AEM 577-01) if it is a journal article or the name of the publication if it is a book.

(ii) Works cited in the text. References to unpublished data, articles submitted for publication, abstracts, personal communications, letters, company publications, patent applications and patents pending, databases, and websites should be made parenthetically in the text as follows:

. . .similar results (R. B. Layton and C. C. Weathers, unpublished data).
. . .system was used (J. L. McInerney, A. F. Holden, and P. N. Brighton, submitted for publication).
. . .in mitochondria (S. De Wit, C. Thioux, and N. Clumeck, Abstr. 34th Intersci. Conf. Antimicrob. Agents Chemother., abstr. 114, 1994).
. . .for other bacteria (A. X. Jones, personal communication).{***see author's note below**}
. . .discussed previously (L. B. Jensen, A. M. Hammerum, R. L. Poulsen, and H. Westh, Letter, Antimi-crob.Agents Chemother. **43:**724–725, 1999).
. . .the manufacturer (Sigma manual, Sigma Chemical Co., St. Louis, Mo.).
. . .this process (V. R. Smoll, 20 June 1999, Australian Patent Office). *{For non-U.S. patent applications, give the date of publication of the application.}*
. . .information found at the XYZ website (http://cbx _iou.pgr).
. . .the ABC program (version 2.2; Department of Microbiology, State University [http://www.stu.micro]).

URLs (Uniform Resource Locators, used for specifying Internet addresses) for companies that produce any of the products mentioned in your study or for products being sold may NOT be included in the article. However, company URLs that permit access to scientific data related to the study or to shareware used in the study are permitted.

***A better way to do personal communications:**

Personal communication: Laird C. 1998, Senior Lecturer, Institute of Land and Food Resources, Dookie College, Victoria. 25 August, c.laird@landfood.unimelb.edu.au.

TIPS FOR HANDLING SPECIFIC TYPES OF DATA:

Dilutions.

If you perform a viable count to determine the number of bacteria in a culture, plate aliquots of the dilutions onto agar with sterile pipettes, spread with glass hockey sticks, incubate at 37°C and count the number of colonies. It is imperative that you utilize your best aseptic technique. Not all bacterial cells produce colonies, as some bacteria tend to clump or aggregate, and some are nonviable. For this reason results are reported as colony forming units (CFU)/ml of bacterial culture. Ideally only plates with 25-250 colonies are used. Counts above 250 are considered Too Numerous To Count (TNTC) because it is impossible to tell whether colonies are separated. Plates with less than 25 colonies do not have a statistically significant number of colonies. When the approximate number of bacteria is unknown, plate a wide range of dilutions. In this way you will have at least 1-2 plates within the countable range (25-250) to use in your calculations. If more than one plate is countable, average the counts together.

In order to make the calculation of the number of cells/ml in the original samples less formidable, dilutions are designed to be easy to handle mathematically. The most common dilutions are 1/10 and 1/100, but any dilution can be made. Because dilutions are large when counting bacteria, exponents are used. Answers should be written with **two significant figures in proper scientific notation, i.e. 1.5×10^8** (Remember: $1 \times 10^a = 10^a$).

a. To Determine Dilution:

$$\text{Dilution} = \frac{\text{Volume transferred}}{\text{Vol. transferred + diluent volume}} = \frac{\text{Volume transferred}}{\text{Total Volume}}$$

Example #1: 1 ml of culture was transferred to 99 ml of diluent.
What is the dilution?

$$\text{Answer: Dilution} = \frac{1 \text{ ml}}{1 \text{ ml} + 99} = \frac{1 \text{ ml}}{100 \text{ ml}} = \frac{1}{100} \quad \text{or } 10^{-2}$$

Example #2: 1 ml of a bacterial culture is transferred to 9.0 ml of diluent. Then 4 serial 10-fold dilutions are made. To arrive at a final dilution, multiply successive dilutions together.

#1		#2	#3	#4	#5
$\frac{1 \text{ ml}}{9 + 1}$	→	$\frac{1 \text{ ml}}{9 + 1}$	$\frac{1 \text{ ml}}{9 + 1 \text{ ml}}$	$\frac{1 \text{ ml}}{9 + 1 \text{ ml}}$	$\frac{1 \text{ ml}}{9 + 1 \text{ ml}}$

1/10	**1/10** X 1/10= 1/100	**1/10** X 1/10 X 1/10 = 1/1000	**1/10** X 1/10 X 1/10 X 1/10 = 1/10,000	**1/10** X 1/10 X 1/10 X 1/10 =1/100,000
(10^{-1})	(10^{-2})	(10^{-3})	(10^{-4})	(10^{-5})

b. General Formula:

$$\text{CFU/ml} = \frac{\text{colonies formed}}{\text{dilution x ml plated}}$$

Example 1: after plating 0.1 ml from a 10^{-5} dilution, 30 colonies grew. How many CFUs were in the original sample?

$$\text{CFU/ml} = \frac{30}{10^{-5} \times 0.1} = \frac{30}{10^{-6}} =$$

$$30 \text{ colonies} \times 10^{6} = 3.0 \times 10^{7} \text{ CFU/ml}$$

Example 2: After plating 0.2 ml of a 10^{-5} dilution, 183 colonies grew.

$$\text{CFU/ml} = \frac{183}{10^{-5} \times 0.2} = \frac{183}{2 \times 10^{-6}} =$$

$$91.5 \times 10^{6} = 9.2 \times 10^{7} \text{ CFU/ml}$$

Growth curve.

Table 2. The results of a growth curve of *Escherichia coli* grown at 37°C on nutrient broth (one ml plated).

TIME (min.)	DILUTION PLATED	# OF COLONIES	AVERAGE CFU/ML
0	10^{-6}	**32, 35, 41**[a]	3.6 X 10^{7}
	10^{-7}	3, 11, 1	
30	10^{-6}	**42, 59, 39**	4.7 X 10^{7}
	10^{-7}	5, 5, 3	
60	10^{-6}	**48, 71, 62**	6.0 X 10^{7}
	10^{-7}	10, 4, 5	
90	10^{-6}	**68, 77, 72**	7.2 X 10^{7}
	10^{-7}	12, 8, 4	
120	10^{-6}	**92, 96, 78**	8.9 X 10^{7}
	10^{-7}	9, 8, 6	

[a]Amounts that are significant are in bold type.

These numbers would then be entered into an Microsoft Excel spreadsheet and the log of the average cell count (CFU/ml) graphed vs. time, using the following instructions:

a. To graph these data, start the spreadsheet software package Microsoft Excel. Directions are for Microsoft Office 2000.

b. **Enter the time points in descending order in column A and corresponding colony counts (or average CFU/ml) in column B**. When entering average CFUs/ml that include exponents, they are entered as X EY. For example, enter the exponent 5.1 x 10^7 by typing 5.1 E7; the display will show 5.1E +07.

c. At this point you would have data in cells A1 to A5 and B1 to B5 (if using the data from Figure 2). With the mouse, start in cell A1 and **drag** the mouse to B5. Your data cells (and only your data cells) should be highlighted.

d. With the mouse choose (**click**) the icon at the top of your screen called "Chart Wizard."

e. **Step 1**: Pick XY (Scatter); 1st chart.

f. **Step 2**: Data range should include your selected data cells ($A$1:$B$5). If data graphed are not correct, click series and enter the correct X and Y values. Time is in X and CFU/ml are in Y.

g. **Step 3**: Add appropriate title, X and Y units. Change axes, gridlines, legend, etc. Click "Finish."

h. **Step 4**: Indicate if you want the chart as a new sheet or as an object in present chart.

i. Once you have your graph, click on the y axis and change scale to logarithmic. You can also add more hatch marks to make it easier to read the graph.

j. If all the points appear to indicate exponential growth, you could click on data points, go to Chart and click on "Add trendline." Choose linear.

k. At this point you can click on "Series 1" box to change to appropriate name or delete. If you click on the graph and choose print, it will size graph to full page.

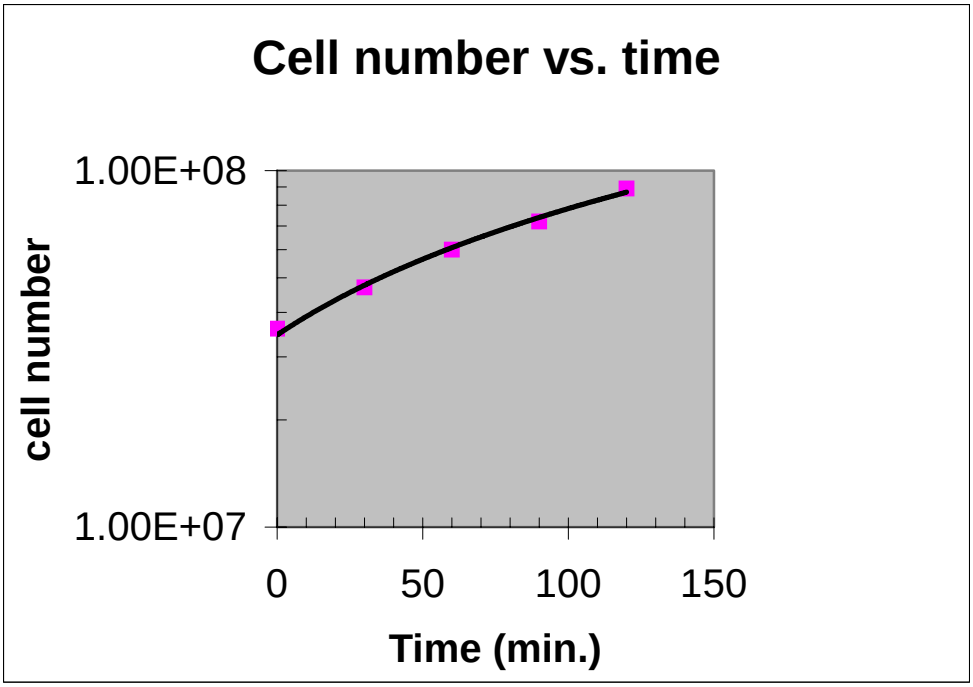

Figure 1. Cell concentration (CFU/ml) over time of *Escherichia coli* grown in nutrient broth at 37^{o}C. Linear trendline added.

You can use the graph to determine the generation time. Choose two points on the graph between which the population doubled and determine the time it took for this to happen. For example at 0 time the cell number was 4 X 10^7 CFU/ml and at 90 minutes it was 8 X 10^7 CFU/ml, so the generation time was 90 minutes.

Electrophoresis data.

When separating DNA, RNA, or proteins by electrophoresis, markers are always included in a separate lane. For DNA, the sample is loaded onto an agarose gel and subjected to an electrical current. All DNA has a net negative charge so the DNA is separated by size and topological form. Numerous markers are commercially available, so DNA size may be determined. Here we will describe a ϕX174 RF DNA/*Hae*III marker set. The replicating form of the ϕX174 virus has been digested with the restriction enzyme *Hae*III. The 11 bands produced by this digest are shown in Figure 2. These fragments are suitable for sizing linear double-stranded DNA from 72-1353 bp. When the gel is finished and a photograph of all bands made, the distance each band has traveled on the gel is graphed vs. the base pair size of each band and a standard curve made (Figure 3). The size of the DNA you have isolated can then be determined by comparing the distance it traveled to the standard curve.

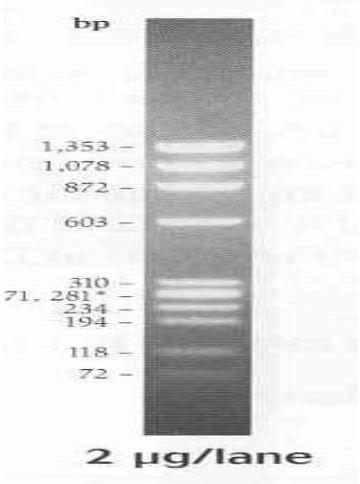

Figure 2. ϕX174 RF DNA/*Hae*III Fragments

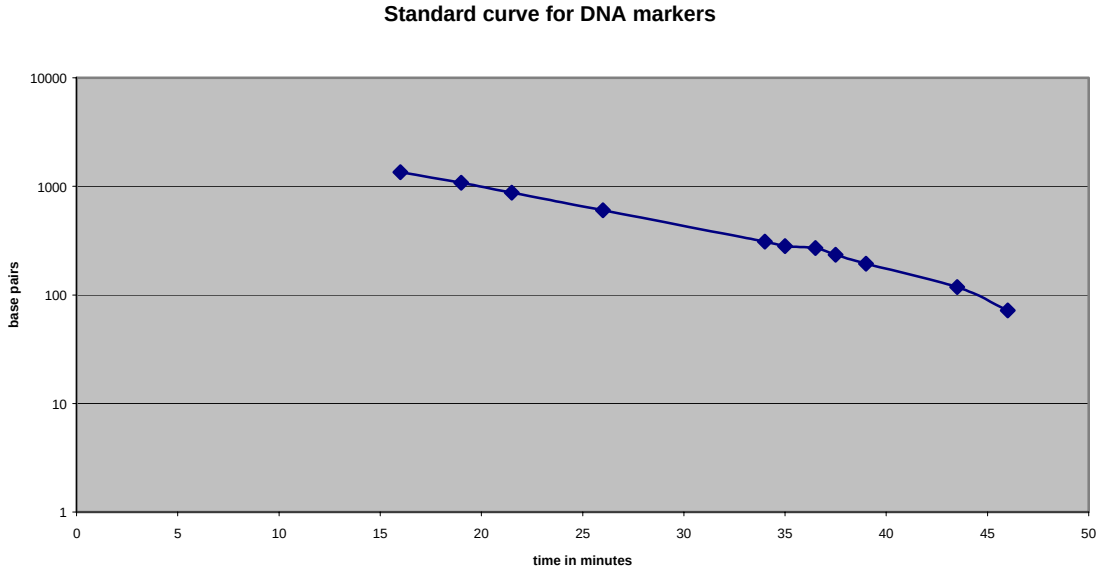

Figure 3. Standard curve of ϕX174 RF DNA/*Hae*III fragments

Statistics.

One of the most common types of statistical analysis done on laboratory data is determination of standard deviation. It is a useful measure of what is called the "scatter of observations," giving an idea of how much importance to place upon variations in repeated observations or replicate experiments. Standard deviation is defined as the positive square root of the variance. The formula is:

s = square root of s^2, where s^2 is the sample variance

The formula for the sample variance is:

$$s^2 = \frac{1}{n-1}\left[\Sigma y_i^2 - \frac{(\Sigma y_i)^2}{n}\right]$$

where n = number of measurements

y_i = each individual measurement

The sample deviation can be determined for an individual sample or for a population. In order to determine standard deviation, one must first calculate the sample mean and the deviation between each sample and the sample mean.

Let's say that you grew 5 different batches of *E. coli*, under identical conditions. The data for the experiment are listed in the first 2 columns of Table 3.

Table 3. The results of *Escherichia coli* grown at 37^{o}C on nutrient broth (one ml plated).

SAMPLE NUMBER	AVERAGE CFU/ML	DEVIATION	STANDARD DEVIATION
1	3.6×10^7	-2.5	6.25
2	4.7×10^7	-1.4	1.96
3	6.0×10^7	-0.1	0.01
4	7.2×10^7	1.1	1.21
5	8.9×10^7	2.8	7.84

The sample mean for these data is achieved by adding all the average CFU/ml (column 2) and dividing by the number *E. coli* cultures grown (column 1):

$$\frac{3.6 \times 10^7 + 4.7 \times 10^7 + 6.0 \times 10^7 + 7.2 \times 10^7 + 8.9 \times 10^7}{5} = 6.1 \times 10^7$$

The deviation for each sampling point (column 3) is obtained by subtracting the sample mean. The standard deviation for each sampling point (column 4) is obtained by taking the positive square root of the deviation. This information can then be added to a graph, to illustrate the difference among the five batches of culture.

Follow the growth curve instructions described above to graph the data (using Microsoft Excel program) listed in columns 1 and 2 (use batch number on the x axis instead of time). Once you have your graph, instead of adding a trendline (step j), add standard deviations to each data point by doing the following:

Double-click on an individual data point. Select "y error bars." Under display, select "both." Click next to standard deviation and then type in the appropriate value. Repeat for each data point.

JOURNAL ARTICLES

Organization

Scientific information in journal articles is normally divided into the following sections: Title, Authors, Abstract, Introduction, Materials and Methods, Results, Discussion and References. Most journals are peer reviewed. That means that they are sent out to at least two other researchers in the field who are well informed on the topic. The researchers carefully read the manuscript to determine if Materials and Methods are well explained and conclusions of data are reasonable.

They may ask the author for further information or to perform additional experiments before the article is accepted for publication.

How to read journal articles

Normally the title, authors and abstract are read first. Then the introduction, results and discussion are read. Finally the methods are read by those who intend to repeat the work or who are unfamiliar with the procedures used. If the title and abstract pique your interest, you will read the introduction to get enough background to understand the rationale for the experiment. You would then skip to the results. This section describes what the author(s) have done. The text should accurately describe the data in the figures and tables. You need to read the results to decide if the data support all statements. In the discussion, the authors will try to convince you of the significance of their data, but you must weigh their evidence and decide whether you agree.

What you find in each section of a journal article

Title: The *title* of the paper is brief but clearly and sufficiently reflects its contents. The title may state the subject of the article or it may give the article's major conclusion. The title is important, for it is the first thing the reader sees, and it helps the reader decide if the article is something they wish to read. Also literature databases use key words from titles to list papers, so a good title will help readers find articles relevant to their interests.

Authors are not a section of a paper but over time authors doing important work are recognized. Literature databases can be searched by author to locate all articles written by a particular author. Normally the individual who did the majority of the work is listed first, and the last author is the principal investigator of the laboratory. The principal investigator is the person in charge of procuring funds and directing the laboratory.

Abstract: The *abstract* should represent a greatly condensed version of the entire paper. It must allow the reader to understand the essence of the authors' research without having to refer to the article. It presents the rationale for the study, reports key results, and points out their significance. Specific details of data are given, but methodology is not described in detail unless it is unique. An abstract should be brief (less than 250 words). The abstract allows the reader to decide if they wish to read the entire paper. Literature databases often supply abstracts online.

Introduction: The *introduction* includes a brief summary of the relevant published literature describing previous research conducted on the problem. The background material, even though it may seem self evident, is referenced. It explains the rationale and justification for the research and usually ends with a statement of the hypothesis that the research was designed to test.

Materials and Methods: The *materials and methods* section is written in enough detail to allow another investigator to duplicate the experiments; however, it is written as text and not in the form of directions. New methods are described completely and sources of unique chemicals and equipment are stated. Standard methodologies (e.g., Gram stain, plate count) are not explained. Methods completely described in previous papers are cited.

Results: *Results* are presented in a sequence that logically supports or rejects the hypothesis. Illustrations and tables that accurately reflect the data are included in results, but they are still referred to in the text. Illustrations and tables are accompanied by a title and an informative legend. Extensive interpretation of data is not given in this section.

Discussion: The *discussion* interprets the meaning of the results and draws conclusions from the data. The authors should show how their observations relate to each other to form a cohesive story. It should address any discrepancies between these results and other papers. The potential implications of the work should be stated.

References: *References* cited in the text are listed in a style dictated by the journal.

FINDING RELEVANT BACKGROUND INFORMATION FOR A LABORATORY REPORT, PAPER OR PRESENTATION

Our first instinct nowadays is to use the web. The web is extremely useful for searching the library for information. You can find what books and journals the library has and check their availability. You can search databases that contain hundreds for journals for key words or author names. For most journals the abstracts are available by web and many journals provide the articles by web. To access these OSU library services use the following web address: http://osulibrary.orst.edu and use the Research Gateway. The databases of most use to microbiologists are AGRICOLA, Biological and Agricultural Index, Biological Abstracts/BIOSIS and Medline. These databases can be searched by subject and limited by dates, language, etc. At the American society for Microbiology web site, http://www.asmusa.org, you can search all ASM journal articles by author or subject. You can use the web to order material by interlibrary loan if our library does not have the particular book or journal you require.

Evaluation of web sites

Many of you want to use the web itself to get information and certainly there is a lot of useful information available on the web. However, anytime you get information from a web site you need to consider the following:

1. You may waste lots of time on useless sites.
2. Who wrote the information – what are their credentials and affiliation? Many websites are simply opinions written by people with few facts to back them up.
3. Even if the person who wrote the information is a Ph.D. at a well-established University, are they writing about material they have expertise in? Do they know what they are talking about? Do they have extensive experience in that particular field of study?
4. Most material on the web is not peer reviewed. If a person submits an article for publication in a scientific journal, prominent scientists working in the same area normally review the article. Most articles are changed before publication. Peer review improves the quality of journal articles, but unreviewed web sites do not benefit from this process.
5. Even if the material on the web is written by an expert and has been peer reviewed, how stable is the site? The author may decide to change the site tomorrow and the information you used will no longer be there.
6. Most scientists who put information on the web will also publish the material in a journal. If they obtained the material from another journal, they will cite the article in their web site. It is always better to consult the original reference.

7. Information on the web may come from a company that is trying to persuade the audience of the value of a product. The information may be biased.

COMMON MISTAKES

Nouns: Singular vs. Plural

A few nouns are often misused in scientific writing. For example, the word *data* is plural while *datum* is singular. Although data can be used to indicate information in general, in scientific writing it is almost always used as a plural. It is correct to write, “These data indicate…” as opposed to “This data indicates…” The words *bacteria, protozoa, fungi,* and *media* are plural while *bacterium, protozoan, fungus,* and *medium* are singular. *Species* and *yeast* can be used both as singular and plural nouns.

Pronouns

Be sure that pronouns refer to preceding words, phrases, or clauses. For example, in the statement, "Sometimes viruses are in white blood cells but they are hard to find," does "they" refer to the viruses or the white blood cells?

Paragraph/Sentence Structure

Be sure to divide paragraphs correctly and to use starting and ending sentences that indicate the purpose of the paragraph. A report or a section of a report should not be one long paragraph.

ETHICS

Reporting Data

In science, the conclusions that a researcher reaches rely on the data gathered. Ultimately that research may influence the opinions of others on particular topics. Therefore, accurate reporting of data is crucial. While this may sound easy, there are always gray areas. As Henry Bauer, a Professor of Chemistry and Science Studies at Virginia Polytechnic Institute, wrote “But what if an experiment doesn't give the result you expected? What if it gives a result that you just *know* is wrong in some way? Isn't there the temptation to fudge a bit? Since you know what the right answer *ought* to be, why not just round the numbers off a bit?” This is a huge ethical dilemma in science, although not one that most scientists would admit.

Obviously, the falsification of any data is unacceptable. If the “rounding of numbers” significantly changes the outcome of the experiment, it is unacceptable as well. It is important that scientific researchers remain as ethical as possible in reporting their data, since that is the only way that real discoveries in science will be made.

Plagiarism

(The following section on plagiarism was modified from a passage obtained from Bill Oye, Oregon State University Student Conduct Program. The original passage was developed in collaboration with faculty in the OSU Department of English.)

If you use words or ideas from another source, you must appropriately credit that source. For example, assume you want to use material from the following paragraph about cell metabolism.

> A knowledge of cell metabolism is essential for understanding the biochemistry of microbial growth. Also, a knowledge of metabolism aids in developing laboratory procedures for preventing the growth of unwanted microorganisms. Because many of the important practical consequences of microbial growth, such as infectious disease or the production of useful products, are linked to microbial metabolism, a knowledge of microbial nutrition and metabolism is also of great use in medical and industrial microbiology.
>
> (Michael T. Madigan, John M. Martinko, and Jack Parker, *Brock Biology of Microorganisms*, 9th edition, Prentice Hall, 2000, p.104)

Acceptable Borrowing: Direct Quotation (remember that this is rare in scientific writing)

> In *Brock Biology of Microorganisms*, the authors say, "A knowledge of cell metabolism is essential for understanding the biochemistry of microbial growth" (1).

> Material borrowed in any form should be identified in the Reference section. The following would be an appropriate listing for a scientific paper (however, you should always consult your instructor or supervisor to see if a particular format should be followed):
>
> 1. Madigan, M.T., J. M. Martinko, and J. Parker. 2000. *Brock Biology of Microorganisms*, 9th edition, p. 104. Prentice Hall, N.J.

Acceptable Borrowing: Paraphrase With Some Quotation

> In *Brock Biology of Microorganisms*, the authors emphasize the importance of knowing about microbial metabolism and nutrition, saying it is “of great use in medical and industrial microbiology” (1).
>
> The source is cited, and that portion which is borrowed word for word is placed in quotes.

Acceptable Borrowing: Paraphrase

> In *Brock Biology of Microorganisms*, the authors emphasize the importance of knowing about microbial metabolism and nutrition, indicating that such knowledge can be used in three areas: (a) determining ways to prevent microbial contamination, (b) developing appropriate methods of growing microbes in the lab, and (c) for application when working with microbes in the fields of industry and medicine (1).
>
> The paraphrase is acceptable and needs only a citation. The paraphrase has not borrowed the wording, sentence structure, or general organization of the source, but it has borrowed the specific ideas. Contrast it with the unacceptable "paraphrase" which follows.

Unacceptable Paraphrase

> In *Brock Biology of Microorganisms*, the authors stress the importance of knowledge of cell metabolism in order to completely understand the biochemistry of microbial growth. They suggest that such knowledge can aid in the culturing of microbes by developing laboratory procedures and in preventing the growth of unwanted microbes by developing suitable procedures. They even say that consequences of microbial growth, such as infectious disease or useful products produced, can be linked to microbial metabolism (1).

This is an unacceptable paraphrase despite the citation at the end. It does not borrow word for word perhaps, but it borrows word after word as it skips through the sentence substituting here and there. Furthermore, it borrows basic sentence structure and general organization.

Unacceptable Borrowing: Plagiarism

> I believe that a knowledge of cell metabolism is essential, without such knowledge one can not understand the biochemistry of microbial growth. Because the results of microbial growth, such as disease or useful products produced by microbes, are linked to microbial metabolism, a knowledge of the nutrition and metabolism of microbes can be very helpful in the fields of medical and industrial microbiology.

This is an obvious attempt on the borrower's part to claim another's ideas. Besides hiding the source of the ideas, the borrower has used another's sentence structure and general organization. Even if the borrower really holds these ideas, such use of another person's work is plagiarism.

ADDITIONAL REFERENCES ON SCIENTIFIC WRITING AND LAB REPORTS

Web sites

1. Dolphin, Warren D., Writing Lab Reports & Scientific Papers, Iowa State University
   http://www.mhhe.com/biosci/genbio/maderinquiry/writing.html
   Information on the standard format of a scientific paper, basic tips.
2. NASA publication: A Handbook for Technical Writers and Editors, Grammar, Punctuation, and Capitalization
   http://stipo.larc.nasa.gov/sp7084/index.html
   Basic information on writing well.
3. Alley, Michael, The Craft of Scientific Writing, Writing Guidelines for Engineering & Science Students
   http://filebox.vt.edu/eng/mech/writing/
   This site contains a lot of valuable information on scientific writing and aspects of scientific writing.

Books

1. **Barass, R**. 1978. *Scientists must write: A guide to better writing for scientists, engineers and students,* Chapman and Hall, New York.
2. CBE Style Manual Committee. 1983. *CBE style manual: A guide for authors, editors, and publishers in the biological sciences*. 5th ed. Bethesda, Md.: Council of Biology Editors.
3. **Cook, Claire Kehrwald**. 1985. *Line by Line: How to improve your own writing,* Houghton Mifflin Co., Boston.
4. **Day, Robert A**. 1994. *How to write and publish a scientific paper,* 4th ed., Oryx Press, Phoenix.
5. **Day, Robert A**. 1992. Scientific English: *A guide for scientists and other professionals,* Oryx Press, Phoenix.
6. **Kanare, Howard M.** 1985. *Writing the Laboratory Notebook,* American Chemical Society, Washington, D.C.
7. **McMillan, V.E.** 1988. *Writing papers in the biological sciences*. New York: St. Martin's Press, Inc.
8. **Reif-Lehrer, Liane**. 1982. *Writing a successful grant application,* Science Books International, Inc., Boston.
9. **Strunk, William Jr., and E. B. White**. 1979. *The elements of style,* 3rd ed., Macmillan Publishing Co., New York.
10. **Young, M.** 1989. *The technical writer's handbook,* University Science Books, Mill Valley, USA.

Reference Books

1. *The New Fowler's Modern English Usage,* 3rd edition. 1996. Edited by R. W. Burchfield, Oxford University Press, Oxford.
2. *Roget's Thesaurus*
3. *Webster's Dictionary*