APPENDIX

Guide to Writing a Scientific Report

Purpose of the Lab Report

No matter what you are writing, you should always know who your audience is so you can write in the way that best communicates with that audience. The "reader" referred to in this guide is a person who understands science but is not as knowledgeable about your particular subject as you are. Your job is to explain your investigation and its significance and to convince the reader that your conclusions are scientifically valid. Since you are writing your lab report for a grade, your instructor is also part of your audience. Your instructor wants to evaluate how well you can communicate your background knowledge and all the components of your investigation to a wider audience, so don't assume that your reader knows as much as your instructor about your investigation. Also keep in mind that writing a good paper depends more on *how well* you designed the experiment and can present and explain the results than on *what* results you obtained. Even if your experiment did not turn out as you expected, you can still write a good lab report.

A scientific report is organized so that each phase of the investigation is described and justified, from formulating a hypothesis through reaching a conclusion about the hypothesis. The exact format used may vary slightly from one source to another. For example, in the format presented here the Discussion and Conclusion sections are separate; in some scientific journals a combined Discussion/Conclusion section is used.

This guide describes the purpose and content of each section of a report and provides a sample paper integrated throughout as an example. The sample report is the material printed in green. Margin notes alongside the sections of the sample report point out features in each part. Read this entire appendix before you begin writing your report. Be sure to read the checklist at the end of the appendix, too. After you've written your report, review the checklist to see whether you've fulfilled all of its criteria.

The sample report is based on a fictitious experiment that was constructed solely to illustrate the composition of a scientific report. The conclusions stated are not based on scientific data.

Sections of the Report

Each section of your report appearing after the title should have a heading.

Title

The title is a statement of the problem you are investigating. It should contain key words that indicate what information the reader will find in the paper. Your hypothesis can be used as a basis for your title.

The title should be placed on a cover page that also includes your name, your instructor's name, and the date.

As an example of turning a hypothesis into a title, consider the following hypothesis: Dark-colored hair dye is more mutagenic to *Salmonella typhimurium* bacteria than is light-colored hair dye. You could reword this for your title:

The title may seem long, but it should give enough information about the investigation for readers to decide whether they are interested in reading the contents of the report.

The Effect of Hair Dye Color on Mutagenicity of *Salmonella typhimurium* Bacteria

Introduction

The Introduction tells the reader what your investigation was about. It provides information about the biological basis for your experiment and a very brief synopsis of your experimental design.

State your hypothesis clearly at the beginning of the Introduction. Follow it with an explanation of why you and your lab team thought this hypothesis was worth investigating.

Give enough background information and references to allow the reader to appreciate the significance of your experiment, including an explanation of any unfamiliar or technical terms. You should relate your investigation to the larger issues in this area of study.

Since you are not an expert, you must cite a reference to show the source of information for any statement you make about the biological basis for your investigation. This demonstrates that you have done your homework and learned about your subject before undertaking your experiment. Citing a reference means telling the reader where you got a particular piece of information. In the text of the report, an abbreviated citation form is used—for example: Campbell, Mitchell, and Reece (1994). A section at the end of the report called Literature Cited gives details about the source of information so the reader can locate it. For your lab reports, your sources will include the lab manual and your textbook. Your instructor may provide additional sources or suggest that you visit the library to get additional information. You may also get information from your professors or other knowledgeable people.

The Introduction should also explain briefly how you intend to go about testing your hypothesis. Finally, state your predictions concerning the outcome of your experiment.

Introduction

This experiment was performed to investigate the following hypothesis: Dark hair dye is more mutagenic in *Salmonella* ***typhimurium*** bacteria than light hair dye.

The hypothesis is stated.

One of our team members had read in the newspaper *(Greenville News,* 1994) that using dark colors of hair dye increases a person's chances of developing certain kinds of cancer. It has been shown that normal cells can be changed to cancer cells by a change or mutation in the genetic material (DNA) of the cell. A chemical or other agent that changes the genetic material is called a mutagen. Mutagens that cause normal cells to become cancerous are called carcinogens (Campbell, Mitchell, and Reece, 1994). In our experiment, we tested the mutagenicity, or ability to cause mutations, of three hair dyes: Basic Brunette (dark color), Bombshell Blonde (light color), and Raspberry Red (a red color in between the dark and light colors).

The author explains what led her to make this hypothesis.

Including this background information helps the reader understand the biological basis for the experiment and demonstrates to the instructor that the author knows the meanings of the terms used. Notice that the citations are set off in parentheses.

We used the Ames test, which is widely used to test whether a chemical causes mutations in *Salmonella* ***typhimurium,*** a species of bacteria. According to Campbell, Mitchell, and Reece (1994), "In general, mutagens are carcinogens." If a chemical is mutagenic in bacteria, then it is studied further to determine whether it could be mutagenic or carcinogenic in animals or humans (Atlas, 1984).

A lab manual by Sigmon (1992) explained how to perform the Ames test using a strain of *Salmonella typhimurium* that cannot make the amino acid histidine as normal *Salmonella* can do. This strain of *Salmonella* bacteria, which is called his- (his minus), can't grow unless histidine is present in agar, the substance it grows on. The part of the bacterial DNA that codes for the ability to make histidine is sensitive to mutagens. A mutagen can cause a mutation that enables the bacteria to produce histidine (Figure 1).

In this paragraph the author demonstrates that she understands the laboratory method used to test the hypothesis. The completeness of the explanation and Figures 1 and 2 will *help the reader understand the author's interpretation of the results when it is presented in the Discussion section.*

Mutation

Salmonella typhimurium strain his-
(can't grow unless histidine is present)

Salmonella typhimurium strain his+
(produces its own histidine)

Figure 1.
Mutation in *Salmonella typhimurium.*

When a mutagen is present during the growth of the bacteria, then the bacteria gain the ability to produce histidine. The mutagenicity of a substance can be tested by growing the bacteria on agar that contains the suspected mutagen but doesn't contain histidine, as shown in Figure 2.

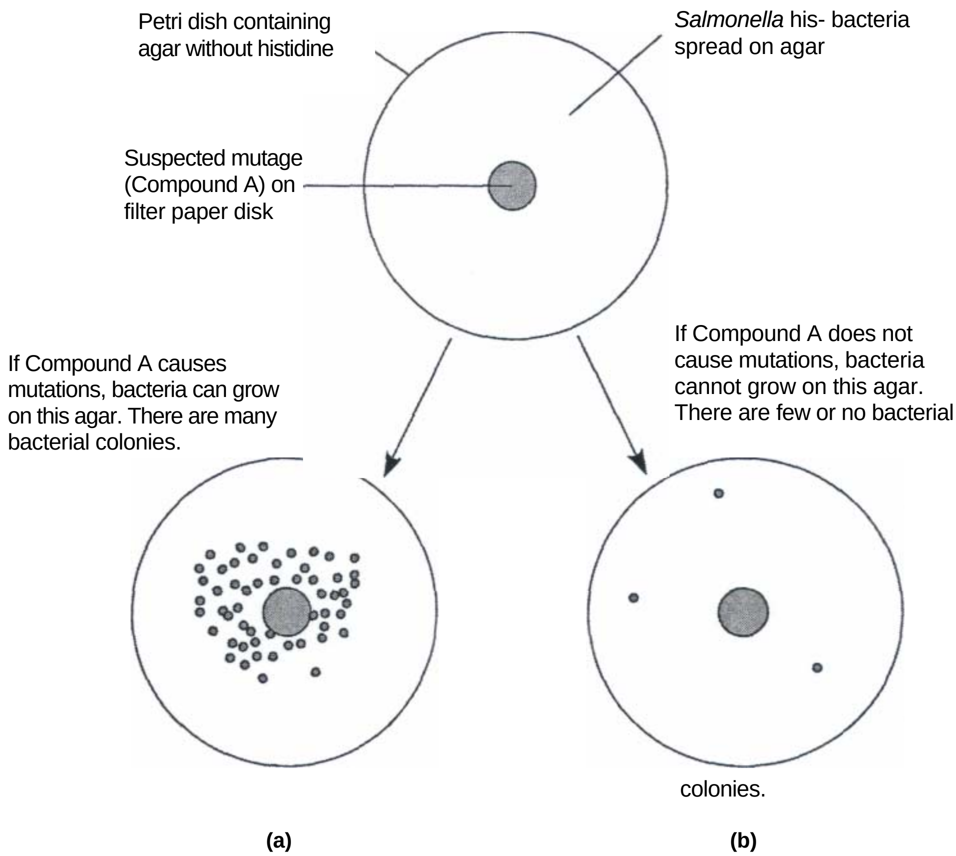

Figure 2.
The Ames test. **Salmonella *typhimuriiun*** is spread on agar that doesn't contain any histidine. Compound A, a suspected mutagen, is placed on a filter paper disk on the agar. If bacterial colonies appear, then Compound A is a mutagen (a). If there are few or no bacterial colonies, Compound A is not a mutagen (b).

We used the Ames test for this investigation and applied brown, red, and blonde hair dyes to the filter paper circles. The growth of the his- strain of *Salmonella typhimurium* on the dishes indicated the ability of these dyes to cause mutations.

If our hypothesis *is* supported, then dishes that contain the brunette hair dye will have the most growth of bacteria, showing that dark dye is most mutagenic. Dishes containing the blonde dye will have the least bacterial growth, and dishes containing the red dye will have an intermediate amount of growth.

Materials and Methods

The purpose of the materials and methods section is to give a detailed account of your experimental procedure. In order to be considered valid, the results of a scientific investigation must be able to be duplicated by other scientists working in other laboratories. It is therefore necessary to provide complete details of how your investigation was performed. In addition, scientists consult the Methods sections of published papers in order to learn techniques they can apply to their own work. So when you write this section, imagine that you are explaining what you did so that someone else can replicate your experiment exactly.

Use the following guidelines for the appropriate style in your Materials and Methods section.

- Use the past tense. Don't write as if you're giving instructions.

  INCORRECT: First you inoculate the agar plates with *Salmonella* bacteria.

  CORRECT: We inoculated the agar plates with *Salmonella* bacteria.

- Tell what you did in paragraph form. Don't write a recipe.

  INCORRECT:

  Step 1. Put 3 drops of hair dye on a filter paper.

  Step 2. Put the filter paper on the agar.

  CORRECT: We put 3 drops of hair dye on a filter paper, and then placed the filter paper on the agar.

- Be specific. Someone attempting to duplicate your experiment needs all the details.

  INCORRECT: We pipetted a sample of broth onto each plate.

  CORRECT: We pipetted a 1-mL sample of broth onto each plate.

Materials and Methods

Twelve Petri dishes containing sterile agar growth medium that lacked histidine were prepared for us by the Biology Department prep staff. We used a broth that contained *Salmonella typhimurium* bacteria (strain his-) to "seed" the agar plates with bacteria. The *Salmonella* cultures were provided by the Microbiology Department. Each member of our group prepared four of the plates using the same technique. Using sterile pipets, we pipetted a 1-mL sample of the broth onto the agar in each plate. The broth was spread over the agar with a glass rod that had been sterilized by dipping the rod in alcohol and then buniing off the alcohol in a flame. The rod was allowed to cool before being used to spread the broth. We learned these techniques from a lab manual (Sigmon, 1992).

AH *the significant details of how the experiment was done* should *be recounted here.*

Following the standard technique for the Ames test (Sigmon, 1992), we used filter paper disks to apply the hair dye to the agar plates. We used 12 filter paper disks, each 1 cm in diameter. Using droppers, we put 1 drop of hair dye or sterile water (for a control) on each disk. Each treatment was thus replicated three times. The filter papers were air dried and then placed in the center of the Petri dishes of agar. Forceps were always used to handle the filter paper.

Cite the source (s) of the techniques you used.

All the hair dyes used were Brand X. We chose Basic Brunette as the dark dye, Raspberry Red as the medium dye, and Bombshell Blonde as the light dye.

The reader should be informed about variables that must be standardized in order to have a successful experiment. If you later think of factors that should have been standardized but weren't, you should mention them in the Discussion section.

Two standardized variables in this experiment were temperature and the time that data were recorded. We put the Petri dishes in an incubator set at 37°C and allowed them to incubate for 7 days. Each day at 11:30 a.m. a team member checked the plates and counted the number of bacterial colonies present. The results were recorded, tabulated, and distributed to the whole team.

Results

In the Results section you present the data in an organized, readable form. Numerical data are usually given in tables. Relationships between factors are often shown on graphs. Graphs, drawings, and anything else that is not a table is called a figure. Tables and figures should be numbered separately so that in the text you can refer to Table 1, Table 2, Figure 1, Figure 2, and so on. All tables and figures must have titles describing their contents.

Remember that you should not include raw data in your report. Also, results must be presented in some numerical fashion. A descriptive narrative is not acceptable.

Keep the following points in mind as you prepare your graphs:

- Use graph paper unless your graphs are computer-generated.
- Label the axes completely.
- Use the entire area of the graph to display your data.
- Choose appropriate intervals and mark them evenly along the axes.
- If there is more than one set of data on the graph, be sure the reader can tell the lines apart. Include a legend (see Figure 3).
- Each graph must have a descriptive title.

In addition to tables and figures, the Results section should include a brief paragraph that draws the reader's attention to the important pieces of data. However, you should save your explanations of *why* results are significant for the Discussion section.

Results

Author briefly points out important results that will be featured in the Discussion section.

Table 1 shows that Basic Brunette had produced the greatest number of colonies at the end of 7 days. Figure 3 shows that bacterial colonies on the dishes containing Raspberry Red and Bombshell Blonde only appeared on the last day, while colonies appeared on the Basic Brunette plates by Day 2 and steadily increased in number.

Table 1.
The total number of ***Salmonella*** his— bacterial colonies counted at the end of 7 days, using 3 replicates for each color of hair dye. The growth medium used was histidine-. Incubation was at 37°C.

Hair dye color	Nuinber of colonies observed
Basic Brunette	36 4* 1 2
Raspberry Red	
Bombshell Blonde	
Water (control)	

* 3 of these colonies appeared to be contaminants.

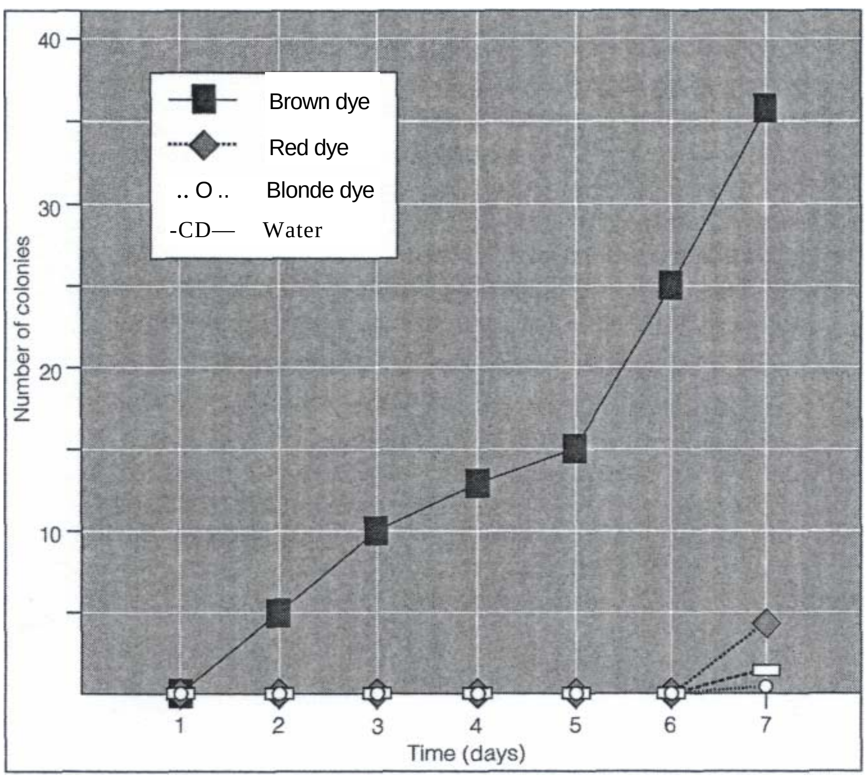

Figure 3.
The total number of Salmonella *typhimurium* his- bacterial colonies (3 Petri dishes per color) counted on each of 7 consecutive days. Incubation was at 37°C on growth medium that lacked histidine.

Discussion

In the Discussion section you should interpret the results, explain their significance, and discuss any weaknesses of the experimental methods or design. From the instructor's point of view, this is the most important section of your paper because it shows how well you understood your investigation. As you might expect, it is also the most difficult section to write.

You should complete the Introduction and Results sections before you begin writing the Discussion. Put them on the desk in front of you, along with your lab notebook open to your notes on the experiment, and begin writing your rough draft. You can outline the contents of the Discussion by taking the following steps.

1. Write down your hypothesis again. Look at the tables and/or figures you constructed for the Results section and determine whether you should accept or reject your hypothesis. (Did your experiment sup port your hypothesis or prove it false?)
2. Check the predictions you wrote in the Introduction section. Do your results confirm your predictions or not?
3. Write down the specific data (using the actual numbers) that led you to your conclusion about the hypothesis. If you have gotten additional results from other lab teams working on a similar problem, list that information also.
4. Write down what you know about the biology involved in your inves tigation. How do your results fit in with what you already know? Be sure to identify the sources of this information.
5. List any weaknesses you have identified in your experimental design. You must tell the reader how these weaknesses may have affected your results. Since your lab experiments are subject to limitations of time and facilities, you will not be able to do a "perfect" experiment. It is important for you to understand, and to acknowledge in your report, how these limitations affect the validity of your conclusions.
6. List any problems that arose during the experiment itself. Unforeseen difficulties with the procedures may have affected the data and should be described for the readers consideration.
7. Review your experimental design and procedure. Consider how you might be able to get more specific or more reliable results by changing the experiment.

Discussion

The *hypothesis is restated along with a brief statement of the investigator's conclusion.*

Our experiment was designed to determine whether dark hair dye is more mutagenic to *Salmonella typhimurium* than light hair dye. Our results supported the hypothesis to the extent that Basic Brunette, a dark brown dye, was more mutagenic than Bombshell Blonde, a light hair dye. The results for Raspberry Red did not support the hypothesis.

Specific data are used in support of the conclusion. The author also explains what the data mean and compares the results to the predictions made before the experiment was performed.

As seen in Table 1, the total number of colonies after 7 days of incubation (36) was greatest in the presence of Basic Brunette, a dark brown hair dye. This result means that the his- gene was mutated to his+ in 36 instances, supporting our hypothesis that the dark color is mutagenic. These results also confirm our prediction.

The plates containing the Bombshell Blonde hair dye and sterile water produced only one or two colonies each. Since the blonde dye did not produce any more mutations than water, which was the control, we can conclude that the blonde dye is not mutagenic. These results also support our hypothesis and prediction.

Raspberry Red hair dye produced four colonies, but three of these colonies, which were all on the same plate, were different colors from all the other colonies. Our lab instructor told us that these three colonies were contaminants, rather than Salmonella typhimurium, so only one of the colonies was actually mutated *Salmonella typhimurium* (Wright, personal communication). Red dye was therefore no more mutagenic than the control. This result was unexpected, since we had predicted that red dye would be intermediate in mutagenicity between brown and blonde.

The source of information obtained through conversation with a knowledgeable person should be cited as a "personal communication."

The list of ingredients on the packages of hair dye gave some insight into the results for red dye. We had assumed that the different colors of dye would have the same pigments but in different amounts. However, Basic Brunette contains two pigments called chemicals A and B, Raspberry Red contains pigments called chemicals C and D, and Bombshell Blonde contains a pigment called chemical E. If we could test just these pigments using the Ames test, we could determine whether chemicals A and B are mutagenic.

When the results are unexpected, you should try to explain why they differ from the prediction. Understanding the reasons for your results, *whatever they are, is an important part of the scientific process.*

For future experiments, we could also test different shades of Brand X hair color containing different pigments or different brands of hair color containing chemicals A and B.

The fact that the control plate produced two colonies suggests that some mutation takes place naturally. Starr and Taggart (1992) state that although some gene mutations are caused by mutagens, "other gene mutations are spontaneous; they are not induced by agents outside the cell." They further add that the rate of spontaneous mutations is relatively low. This supports the results from the plates containing water and Raspberry Red and Bombshell Blonde hair dyes.

The author uses this background information to show how her results fit in with what is already known on the subject.

Figure 3 shows that five colonies had appeared in the Basic Brunette dishes by Day 2, and the number of colonies increased steadily over the entire 7 days of the experiment. The significance of this result is that the bacteria present were being mutated over time as the hair dye diffused to a wider and wider area of each dish. This means that the longer the bacteria are exposed to hair dye, the more mutations will occur. If we repeated this experiment, we would draw concentric rings around the filter paper disks and count the colonies appearing in each ring over time instead of just taking a total count of the dish.

Again, the author discusses *specific data and interprets it using her knowledge of biological concepts. This leads to another suggestion for improving the experiment.*

The Ames test is not a definitive test for the cancer-causing ability of any chemical. It does indicate w[7]hether a chemical is mutagenic (can cause changes in the DNA). The Basic Brunette hair dye definitely showed signs of being mutagenic to Salmonella DNA, especially when there is longer exposure. Raspberry Red and Bombshell Blonde hair dyes gave no evidence of being mutagenic. Our results support the study cited in the *Greenville News* (1992), which found that some hair dyes are potential carcinogens.

Author explains how the results of this investigation support published information.

Weaknesses in our experiment include the length of time allowed for incubation, the number of ingredients contained in the hair dyes, the fact that only one brand of dye was tested, and the contamination of one of the Petri dishes. We could extend this experiment by testing the individual pigments in the hair dyes, using different brands of hair dye, testing the *Salmonella* his+ strain, and counting the colonies in concentric rings away from the hair dye disks.

Weaknesses of the experiment are pointed out. This shows that the author understood the method and results well enough to improve the experiment.

Conclusion

Your conclusions may be mentioned in three sections of your paper: Introduction, Discussion, and Conclusion, but they must be stated in the Conclusion. In the Conclusion section, try to rephrase your conclusion rather than repeat the exact wording used in a previous section. If your readers did not understand your initial version, another wording may clarify it.

The Conclusion should be brief (two or three sentences). It should repeat the significant results from your experiment, but should not contain any new information.

Conclusion

Basic Brunette caused 36 colonies of his- bacteria to grow on agar lacking histidine, so we concluded that this hair dye caused a mutation in the bacterial DNA. Raspberry Red and Bombshell Blonde dyes each produced a total of one mutated colony, so we concluded that these two dyes are not mutagenic.

Literature Cited

You must tell the reader exactly where to find the sources of information you used. In the text of the report, cite the source as (author, date) or author (date). For example:

(Author, date): A chemical that causes normal cells to become cancerous is called a carcinogen (Campbell, Mitchell, and Reece, 1994).

Author (date): Campbell, Mitchell, and Reece (1994) define a carcinogen as a chemical that cause normal cells to become cancerous.

At the end of the report, the Literature Cited section gives detailed information about the sources of information you used. The sources should be listed alphabetically by author. Any source that appears in your list must also be cited in the text of the report. The following examples illustrate one style. You may see slightly different citation styles used in different sources. Note that all citation styles include die same information; it is simply arranged differently. If you have a word processor with italics, use italics for titles, which are underlined here.

Literature Cited

Atlas, C. Microbiology. New York: Macmillan Publishing Company, 1984.

Campbell, N., L. Mitchell, and J. Reece. Biology: Concepts and Connections. Redwood City, CA: Benjamin/Cummiiigs, 1994.

Greenville News. "New Study Links Hair Dye and Cancer." Greenville, SC: Greenville-Piedmont Publishing Company, June 4, 1994.

Sigmon, J. Laboratory Techniques in Microbiology. Clemson, SC: Clemson University, 1992.

Starr, C., and R. Taggart. Biology:.The Unity and Diversity of Life, 6th ed. Belmoiit, CA: Wadsworth. 1992.

Wright, I. M., biology professor at Clemson University, personal communication, 1994.

Using Reference Materials Honestly

When your instructor reads your paper, he or she wants to evaluate your understanding of the biology involved in your experiment. It is essential for you to use your own words to explain your investigation rather than attempting to imitate your references. In addition, you could face a charge of plagiarism if "your" work is too similar to someone else's work.

Avoiding Plagiarism

Many students have difficulty trying to put information they've read into their own words. Typically, they change or rearrange a few words but leave the sentence essentially the same as it was written. For example, here is a sentence from a biology textbook (Campbell, Mitchell, and Reece, 1994): "Cancer-causing agents, factors that alter DNA and make cells cancerous, are called carcinogens." A student changed this sentence to read "Factors that cause cancer and alter DNA to make cells cancerous are called carcinogens." The student has tried to disguise this sentence from the textbook as his own work. Not only is the deception transparent to someone who has read the textbook, the awkwardness of the resulting sentence might even make the instructor wonder if the student knows what he is saying.

How can this problem be avoided?

- Take notes from your references, and then write from your notes rather than writing directly from the reference.
- Use more than one source of information for each topic so you won't get stuck on certain phrases.
- Think about what you know before you write it down. Digest and resynthesize the information you have read.
- Write down what you know quickly, without worrying about how well it's written. Later, revise your writing so a reader can understand it.

Using Quotations

Any sentence or phrase that is copied directly from a source must be placed in quotation marks.

The use of lengthy quotations indicates to the instructor that the student doesn't understand the subject well enough to explain it himself. For the lab reports you'll write for this course, it's recommended that direct quotations be no longer than one sentence.