HOW TO WRITE A SCIENTIFIC PAPER

Some of the details of format differ depending on the scientific journal in which a paper is to be published, but the information given here applies to most scientific papers and is the method that you will be expected to use in this course.

A scientific paper (research report) is a method of communication, an attempt to tell others about some specific data that you have collected and what you think that data means. As a method of communication, the paper obviously requires proper usage of the English language (and such usage will be considered in the final grading of your report). The report should be written in a clear, concise manner (no flowery language) so the reader can easily understand what you have done and how you have done it, in case he or she should want to repeat or extend your work. To enable the reader to comprehend the main points of someone's work quickly, the scientific paper is arranged in a very standardized format as follows:

Title
Introduction
Methods And Materials
Results
Discussion
Conclusions
Literature Cited

The above format is the one you will be required to use for your report. Note that all the section headings (Introduction, Results, etc.) are always centered on their respective pages; the body of each section then follows immediately behind the section heading. Do not begin each section on a new page. If one section ends part of the way down one page, then the next section heading follows immediately on that same page. Note, too, that a scientific paper does not use a table of contents.

Now, let's take a closer look at the details.

Title

Every scientific paper must have a title. The most important thing about the title is that it be self-explanatory. That is, the reader should be able to tell, just by reading the title, what you have done without having to read the paper itself. A title such as A Biology Lab Report for example, tells the reader nothing. He has no idea of whether your work involved an animal or a plant, or what you were measuring or testing. An example of a good, self-explanatory title would be: The Effects of Light and Temperature on the Growth of the Bacterium Escherichia coli. Here the title explains exactly what the worker has done: he has manipulated two environmental factors (in this case, light and temperature) to see what the effects will be on the growth of a specific organism (in this case, a bacterium known as Escherichia coli.) Note that the title specifically states three things:

1. The environmental factors that were manipulated: in this case, light and temperature;

2. The parameter of the organism that was measured: in this case, growth;

3. The specific organism that was used: in this case, Escherichia coli.

If the title, for example, had only said Effects of Light and Temperature on Escherichia coli, then the title would not have been completely self-explanatory. The reader would have been forced to guess what parameters of the organism were measured by the researcher. Was the researcher concerned with the effects of light and temperature on reproduction of the organism, the feeding ability of the organism, survival, weight, or what have you? Similarly, if the title had said Effects of Environmental Factors on Growth of Escherichia coli, the reader would not know what environmental factors were manipulated. If the title had said Effects of Light and Temperature on Growth of an Organism, then the reader would not know what organism was used. In fact, he wouldn't even know if the organism was a plant or an animal. In any of these hypothetical instances the reader would be forced to read the paper to understand what the researcher had done; the title alone would not have been sufficiently explanatory.

There are exceptions; one does not always have to state all the specific factors that were manipulated if a large number of variables was used. For example, something like this would be acceptable: Effects of Various Chemicals on the Growth of Escherichia coli (if several chemicals were used instead of only two or three); or, Effects of Several Environmental Factors on Growth of Escherichia coli (if several factors were studied, such as light, temperature, water, pH, type of food, minerals, etc.). In cases such as these, the title would be too long if it included every variable that was used in the experiment. The same applies if more than two or three kinds of animals or plants were used in the study. For example, a title such as this would be acceptable; Effects of Light and Temperature on Growth of Several Species of Bacteria. The researcher would then include the names of the several bacteria in the text of the paper.

Introduction

The introduction is the statement of the problem and contains background information concerning the problem. The researcher states the purpose of the investigation, that is, the specific question(s) he is trying to answer. He also describes everything he has been able to find out concerning the problem (this is usually accomplished by a literature search in the library), including any research that has been done on the problem in the past, and discusses how his present experiment will help to clarify or expand the knowledge in this general area. All background information that the researcher has gathered from other sources (textbooks, journals, etc.) must, of course, be appropriately referenced (see the section on how to cite references).

Methods and Materials

In this section the researcher explains how (and sometimes when) he did his work. He describes his experimental design, his experimental apparatus, his methods of gathering data, and the type of control (if any) that he used. If any work was done outdoors in a natural habitat the researcher describes the study area, states its location, and explains when he did the work. If any specimens were collected for the study, the researcher states where and when that material was collected. In this section, photographs, maps, diagrams, etc. can be used as an aid in describing the experimental setup. The rule to keep in mind is this: the Methods and Material section should be detailed and clear enough so that any reader would be able to duplicate the experiment if he wished to do so.

Keep in mind another important rule: the Methods and Material section should be written in a past tense. A scientific paper is a report on something that the researcher has done in the past. The paper should read essentially like a narrative, in which the researcher "tells his story." He describes what he did and what results he obtained from that work.

The scientific paper should not be written as though it were directions in a laboratory manual. For example:

> First pour agar into six petri plates. Then inoculate the plates with the fungus. Then you put the plates into the incubator (etc.).

This sounds as though the author is leading someone by the hand, telling him how to do the experiment. A scientific paper is not written in this manner. The researcher simply describes, either in first person or in passive voice, how he did the experiment. For example:

> I filled six petri plates with agar and inoculated them with the fungus. I then incubated the plates for ten hours.
>
> or
>
> Six petri plates were prepared with agar and inoculated with fungus. The plates were placed in the incubator for ten hours.

Most Methods and Materials sections are written in the passive voice.

Another rule for the Methods and Materials section: do not make a list of equipment used in the experiment. For example:

> For this experiment you will need the following equipment:
>
> 6 petri plates
> 1 liter of agar
> 2 inoculating loops, etc.

This, too sounds like a laboratory manual; scientific papers are not written in this manner. The materials that were used in the research are simply mentioned in the narrative as the experimental procedure is explained in detail. The reader, if he wishes to, can make a list of necessary materials as he reads the section.

Remember:
1. Do not make lists of materials;
2. Write in a past tense or in passive voice when describing your Methods and Materials.

Results

Here the researcher presents his data for inspection by the reader. The results are presented in a straightforward manner, with no conclusions or value judgments as to what the data might mean (conclusions are reserved for the Discussion and Conclusions sections). If possible, the data is assembled into tables and/or graphs to supplement the text and to present the data in an easily understandable form. If tables and/or graphs are used, they must be accompanied by a narrative text. A Results section that includes only a table or a graph and no text along with it is not acceptable in a scientific paper. The text

describes the results that are presented in the tables and graphs and calls attention to what the researcher considers to be the significant data that he will talk about in the Discussion section. For example, the text might read as follows:

> The results of the temperature experiment are shown in Figure 1 (Figure 1 might refer to a graph in which the data is presented). The number of bacterial colonies increased up to 40° C but decreased at high temperatures (here the author is specifically calling attention to the significant results so the reader can easily see the important data in the graph). The greatest amount of growth occurred between 35° and 40° C.

When tables and/or graphs are used, certain rules must be adhered to. These will be explained in a later section of this guide.

Discussion

Here, the researcher explains what he thinks his results mean. He describes any patterns that emerged, any relationships that he thinks were meaningful, and any correlations that he could discern. This includes any explanations as to why he thinks the results turned out differently (if they did so) from the way he expected, (the incubator broke down, or he forgot to add a certain chemical, etc.) or why the results were either different from or similar to any related experiments that have been done by other workers. He compares his results to the information already known about the problem, such as past experiments or observations conducted by himself or other workers (the background information that was mentioned in the Introduction section). He makes conclusions about the meanings of his data and explains why he has reached those conclusions. In effect, the researcher is defending his point of view in the Discussion section.

Conclusions

This section is, in a way, a partial repeat of the Discussion section. The researcher simply states again all his conclusions, but without any of the reasons as to why he reached those conclusions. This section presents all the important conclusions, the significant discoveries, that the researcher wants the reader to know. In effect, the Conclusions section enables the reader, if he doesn't have the time to read the entire paper, to quickly determine what the researcher has discovered. The Conclusions section is, in a sense, a capsule version of the Results and Discussion; it is a time-saver for the reader. By looking at just the Introduction and Conclusions sections, a reader should have a pretty good idea of what the researcher has done although he might not know the details of how the work was done.

In the Conclusions section the researcher might also suggest further investigations that could be done on the general problem and what contribution he has made to the problem with his present research.

Literature Cited

This section lists, in alphabetical order by author, all published information that was referred to anywhere in the text of the paper. It provides the reader with the information he needs if he should want to conduct a literature search on the general problem. Note that the Literature Cited sections includes only those references that were actually mentioned, or cited, in the paper. Any other information that the researcher may have read concerning the problem but did not mention (cite) in the paper, is not included in this section. This is why the section is called Literature Cited, instead of References or Bibliography.

The details of punctuation, order of information, etc., in the Literature Cited section are fairly complex and will be explained to you by your laboratory instructor. A typical Literature Cited section would look something like this:

Bartholomew, G. A., and T. J. Cade, 1963. The water economy of land birds. Auk, 80:504.

_____, and W. R. Dawson, 1953. Respiratory water loss in some birds of southwestern United States. Physiol Zool., 26:162

Cade, T. J. and G. A. Bartholomew, 1959. Sea water and salt utilization by Savannah Sparrows. Physiol. Zool., 32:230.

Humason, G. L. 1962. Animal tissue techniques. W. H. Freeman and Co., San Francisco.

Marler, P., and W. J. Hamilton, Ill. 1966. Mechanisms of animal behavior. John Wiley and Sons, Inc., New York

Oksche, A., D. S. Farner, D. L. Servenity, F. Wolff, and C. A. Nicholls, 1963. The hypothalamo-hypophysial neurosecretory system of the Zebra Finch, Taeniopgia castanotis, Z. Zelforsch., 58:846.

Poore, J. T. 1969. The effects of water deprivation on the hypothalamic-hypophysial neurosecretory system of the Black-throated Sparrow. Amphispiza bilineata. Master's thesis, The University of Arizona, Tucson.

Wynne-Edwards, V. C. 1935. On the habits and distribution of birds in the North Atlantic. Proc. Boston Soc. Nat. Hist. 40:233.

How To Cite References

Any time a researcher mentions any information in his paper that is not information that he has actually obtained himself (via his own experiments or observations) the researcher must include a reference to indicate the source of that information. This is referred to as citing the reference.

The first rule to remember when citing references in a research report is this: scientific papers do not use footnotes!

There are several ways that references can be cited in a scientific paper. The method used is usually determined by the scientific journal in which that paper is to be published. The method described here probably applies to most scientific papers (at least biology papers) and is the method that you will be expected to use in your reports.

If you have stated some information that needs referencing, put the names(s) of the author(s) of that information in parentheses at the end of the statement. The name(s) should be followed by the year of the publication in which that information appeared. For example:

> Some birds are primarily insectivorous and probably obtain all the water they need from the body fluids of the insects they eat (Jones and Smith 1963).

This tells the reader that Jones and Smith are the originators of that statement and that they published the information in 1963. If the reader wants to see the actual publication in which this information appeared, he can turn to the Literature Cited section and find the name of the actual article and journal. The reader can then look it up for himself. In some cases, you may have mentioned the name(s) of the worker(s) in the statement itself. In that case, simply put the date of the worker's publication in parentheses following the individual's name. For example:

> Jones and Smith (1963) found that some birds obtain all the water they need from the body fluids of the insects they eat.

If you must reference more than one publication, or more than one point of information in the same sentence, simply put the citations in the appropriate parts of that sentence. For example:

> Although Jones and Smith (1963) state that not all birds have to drink water, several other studies (Taylor 1964; Smith and Smith 1968; Altert et al, 1969; Thompson 1970) have pointed out exceptions. The metabolic rate of the species seems to play a role (Harrington 1965) as well as the food source (Montgomery and Landers 1966).

If there are three or more authors to be cited for any one reference (such as Oksche, Farner, Serventy, Wolff and Nichols 1963), the citation is usually abbreviated as follows:

> The Zebra Finch was found to differ in these respects from the species observed in this study (Oksche et al. 1963).
>
> or:
>
> Oksche et al. (1963) report different results with the Zebra Finch.

In this case only the name of the first author (usually referred to as the senior author) is used, followed by the abbreviation et al. This abbreviation indicates to the reader that three or more persons were involved in the study. When this reference is listed in the Literature Cited section, however, all the names of the workers must be included. The et al. abbreviation is used only in the text of the paper.

If you mention any information in your paper that was given to you by personal communication (letter, telephone conversation, personal meeting, etc.) you must also cite that reference. This can be done as follows: "Jones (personal communication) has shown that some birds never have to drink water," or, "Some birds apparently never have to drink water (Jones personal communication)." Citations of personal communication are not listed in the Literature Cited section because the information mentioned is not published.

The Use of Tables and Figures

When a researcher presents his data to the scientific world he tries to make that data as easily understandable as possible. He puts the data into a form that easily shows the reader any correlations or relationships or patterns that are important. Two widely used methods for doing this are tables and graphs. Whenever possible, data in a scientific paper should be put into some sort of tabular or graphical form. Whenever these methods are used in a scientific paper, however, certain requirements must be adhered to.

1. Tables are referred to as tables: all other items (graphs, pictures, drawings, maps, etc.) are referred to as figures.

2. Whenever a table and/or figure is included in the scientific paper, there must be some reference to that table or figure in the text of the paper. For example, "The results of the temperature experiment are shown in Figure 1" or "The results of the temperature experiment (figure 1) are somewhat confusing." This tells the reader that all the data have been put together in one part of the paper known as Figure 1--a graph, perhaps--and that the reader should refer to that figure to see what results were obtained and what patterns were discerned.

3. Tables and figures are numbered independently of each other. For example, assume that your paper contains three tables and two figures. The tables would be numbered table 1, table 2 and table 3. The figures would be numbered figure 1 and figure 2, not figure 4 and figure 5.

4. Tables and figures are assigned their respective numbers on the basis of the order in which they are first mentioned in the text. The first table to be mentioned is table 1, the second is table 2, etc. The same applies for the figures.

5. Tables and Figures can all be put together at the end of the paper, but it is much more desirable to place the tables and figures as close as possible to the actual page where the table or figure is mentioned in the text. This makes it easier for the reader to refer to the table or figure when it is mentioned in the paper.

6. All tables and figures must be numbered and must have self-explanatory titles. The rules for composing the title are the same as for composing the title of the paper itself. In other words, the reader should be able to look at a table or figure and, simply by reading the title, know exactly what was done in that part of the experiment without having to read the text of the paper for explanation.

7. All tables and figures should include the units of measurement involved (grams, meters, seconds, etc.). Otherwise the data will mean nothing to the reader. All columns in a table should have separate legends, and both axes (x-axis and Y-axis) of a graph must have separate legends.

8. Tables are always labeled at the top. Figures are always labeled at the bottom.