

HOW DO I WRITE A SCIENTIFIC PAPER?

As you know, one important method by which scientists communicate with one another is via scientific reports (also called "scientific papers"), published in professional magazines, called "journals". In a scientific report, the researcher(s) tell the reader what they did, what they found out, and what they think it all means. Scientific reports are written in a very different style from reports or papers in literature or history, so we provide you with these guidelines to approved organization, format, and style. Please notice, however, that nowhere in these guidelines do we say that a scientific report should be dry, stuffy, and difficult to read!

A scientific paper is a written report describing original research results whose format has been defined by centuries of developing tradition, editorial practice, scientific ethics and the interplay with printing and publishing services. The result of this process is that virtually every scientific paper has the following components: (1) title, (2) abstract, (3) introduction, (4) methods, (5) results, (6) discussion, (7) conclusions, (8) acknowledgements, and (9) literature cited.

It should, however, be noted that most publications have rules about a paper's format: some divide papers into these or some of these sections, others do not, and the order may be different in different publications. So be prepared to revise your paper into a publication's format when you are ready to submit.

One general point to remember is the need to avoid jargon and acronyms as much as possible. A second is the fact that some journals like papers to be written in the active voice - i.e. "we carried out a test..." rather than "test was carried out to..." — but that this is not always the case.

Style

In all sections of the paper, present tense should be used to report background that is already established. For example, "The cell membrane is the barrier which separates the inside of the cell from the outside." Use future tense for work that you will do. For example, "We will test the hypothesis that some anti-microbial agents can permeate the cell membrane during division to inhibit growth." Use past tense to describe results of a specific experiment, especially your own. For example, "Application of the antibiotic Chloramphenicol restricted growth of *E. coli*."

Page numbers should not appear on the first or cover page. For a short paper, a "Table of Contents" is generally not necessary. Print your paper double-spaced, with at least 1-inch margins, in an easy-to-read, 12-point font.

Captioning

Captioning is a method of separating the body of a paper into sections. Headings show organization and identify the topic for a section or a block of information. Capital letters, underlining, point size, and position on the page help to differentiate rank or level.

Title

A title should be the fewest possible words that accurately describe the content of the paper. Omit all waste words such as "A study of ...", "Investigations of ...", "Observations on ...", etc. Indexing and abstracting services depend on the accuracy of the title, extracting from it keywords useful in cross-referencing and computer searching. Avoid cutesy titles.

An improperly titled paper may never reach the audience for which it was intended, so be specific. If the study is of a particular species or chemical, name it in the title. If the study has been limited to a particular region or system, and the inferences it contains are similarly limited, then name the region or system in the title.

Keyword List

Some journals require a keyword list. The keyword list provides the opportunity to add keywords, used by the indexing and abstracting services, in addition to those already present in the title. Judicious use of keywords may increase the ease with which interested parties can locate your article.

Abstract

The abstract states the principal objectives and scope of the investigation, describes the methodology employed, and summarizes the results and principal conclusions. A well-prepared abstract enables the reader to identify the basic content of a document quickly and accurately, to determine its relevance to their interests, and thus to decide whether to read the document in its entirety. The abstract concisely states the principal objectives and scope of the investigation where these are not obvious from the title. More important, it concisely summarizes the results and principal conclusions. Do not include details of the methods used unless the study is methodological, i.e., primarily concerned with methods.

The abstract must be concise; most journals specify a length, typically not exceeding 250 words. If you can convey the essential details of the paper in 100 words, do not use 200. Do not repeat information contained in the title. The abstract, together with the title, must be self-contained as it is published separately from the paper in abstracting services such as Biological Abstracts or Current Contents. Omit all references to the literature and to tables or figures, and omit obscure abbreviations and acronyms even though they may be defined in main body of the paper. As a summary of work done, abstracts are generally written in past tense.

Introduction

The introduction begins by introducing the reader to the pertinent literature. A common mistake is to introduce authors and their areas of study in general terms without mention of their major findings. For example: "Parmenter (1976) and Chessman (1978) studied the diet of *Chelodina longicollis* at various latitudes and Legler (1978) and Chessman (1983) conducted a similar study on *Chelodina expansa*" compares poorly with: "Within the confines of carnivory, *Chelodina expansa* is a selective and specialized predator feeding upon highly motile prey such as decapod crustaceans, aquatic bugs and small fish (Legler 1978; Chessman, 1984), whereas *C. longicollis* is reported to have a diverse and opportunistic diet (Parmenter 1976; Chessman 1984)". The latter is a far more informative lead-in to the literature, but more importantly it will enable the reader to clearly place the current work in the context of what is already known. In string cites (more than one reference), cites are generally listed from oldest to newest.

Try to introduce references so they do not interfere with the flow of your argument: first write the text without references so that it reads smoothly, then add in the references at the end of sentences or phrases so they do not interrupt your flow. Note that not all journals use author's names in references, some use numbers in the text with a list of citations at the end of the article. Check the publication's style when you are ready to submit your paper.

An important function of the introduction is to establish the significance of your current work: Why was there a need to conduct the study? Having introduced the pertinent literature and demonstrated the need for the current study, you should state clearly the scope and objectives.

Avoid a list of points or bullets; use prose.

The introduction can finish with the statement of objectives or, as some people prefer, with a brief statement of the principal findings. Either way, the reader must have an idea of where the paper is heading to follow the development of the evidence.

Methods

The main purpose of the methods section is to provide enough detail for a competent worker to repeat your study and reproduce the results. The scientific method requires that your results be reproducible, and you must provide a basis for repetition of the study by others.

The usual order of presentation of methods is chronological. However, related methods may need to be described together and strict chronological order cannot always be followed. If your methods are new (i.e. unpublished), you must provide all the detail required to repeat them. However, if a method has been previously published, only the name of the method and a literature reference need be given.

For measurements, be precise as possible. Questions such as "how" and "how much" should be precisely answered by the author and not left for the reader to puzzle over. Ordinary statistical methods should be used without comment; advanced or unusual methods may require a literature citation.

In sum, state what you did and how you did it in a way that a reader can repeat the study. Do not include discussion, rationale, excuses, etc. Do not include why you conducted the study, how it turned out, how you interpreted the results, or the rationale. All of these should be in the results or discussion sections.

Results

In the results section, you present your findings: display items (figures and tables) are central in this section. Present the data, digested and condensed, with important trends extracted and described. Because the results comprise the new knowledge that you are contributing to the world, it is important that your findings be clearly and simply stated.

The results should be short and sweet. Do not say "It is clearly evident from Fig. 1 that bird species richness increased with habitat complexity". Say instead "Bird species richness increased with habitat complexity (Fig. 1)".

However, don't be too concise. Readers cannot be expected to extract important trends from the data unaided. Few will bother. Combine the use of text, tables and figures to condense data and highlight trends. In doing so, be sure to refer to the guidelines for preparing tables and figures below. Remember, nothing but results goes into the results section!

Discussion

In the discussion, you should discuss what principles have been established or reinforced; what generalizations can be drawn; how your findings compare to the findings of others or to expectations based on previous work; and whether there any theoretical/practical implications of your work.

When you address these questions, it is crucial that your discussion rests firmly on the evidence presented in the results section. Refer briefly to your results to support your discussion statements. Do not extend your conclusions beyond those that are directly supported by your results.

A brief paragraph of speculation about what your results may mean in a general sense is usually acceptable, but should not form the bulk of the discussion. Be sure to address the objectives of the study in the discussion and to discuss the significance of the results. Don't leave the reader thinking "So what?"

The discussion section is usually the most difficult part to write. The components of a good discussion usually contain these elements:

1. Presentation of the principles, relationships and generalizations shown by the results.
2. Point out any exceptions or lack of correlation and define any unsettled points. Try to explain why those specific or unsettled points do not correlate, and suggest what you can do to avoid these lack of correlations if experimental errors were involved.
3. Show how your results and interpretations agree or contrast with previously published work. Try to present reasonable explanations why your results do not agree with comparable results by other researchers.
4. Discuss the theoretical implications of your work as well as practical applications. This provides the basis on why your work is important and why your investigations are important in context with other people's research.

In sum, what did you find? How do results relate to those reported previously? Was the hypothesis correct? Does it need to be changed and what are the appropriate changes? Are all tables, graphs, and other illustrations absolutely necessary to understand the study? Is information in the tables, graphs, and text redundant or repetitive? Are statistical differences/significances clear?

Conclusion

Many journals combine the conclusion with the discussion section. However, we require a separate section for your conclusions. State your conclusions as clearly as possible and summarize your evidence for each conclusion. Be sure you answer the question: "so what?" What recommendations/advice to the reader can you make on the basis of your findings? The conclusion usually draws general principles from particular findings. This section can be (and usually is) quite short.

Acknowledgements

This is a brief section of one or a few sentences, in which you acknowledge all the help you received during the study's planning, execution, analysis, and writeup (including funding sources). The existence of this section illustrates two important things. First, it is perfectly allowable, and indeed a good idea, to brainstorm with others about your project at its different stages, because such brainstorming can stimulate lots of good ideas. Second, never misrepresent ideas you get from others as your own; always give credit to the sources of those ideas.

Literature Cited (and citations within the paper)

A list of literature cited, which is ordered alphabetically by author's surname, or by number, depending on the publication, must be provided at the end of your paper. The list should contain ONLY references cited in the text. If you did not cite a reference in the text, do not include it in the literature cited section. Include with each reference details of the author, year of publication, title of article, name of journal or book and place of publication of books, volume and page numbers.

References must substantiate, relate to, or confirm the assumptions in your study. Be thoroughly familiar with a source before citing it. There are standard abbreviations for most journals, but if you don't know it, spell them out and be consistent when abbreviating them. Usually, the standard format for a reference is author's last name, first and middle initials, title of the paper, journal of where the paper was published (in italics), year, volume (and number if necessary), page number (beginning to end). For example:

Nondek, L., D.R. Rodler, and J.W. Burks. 1992. Measurement of sub-ppbv concentrations of aldehydes in a forest atmosphere using a new HPLC technique. *Environ.Sci. and Technol.* **26**:1174-1178.

There are usually three ways to cite a reference within your paper: name and year; alphabet-number; and citation order. The choice is usually determined by the journal. The name and year system is simple. The alphabet-number system is a citation by number from an alphabetized list of references. If two authors are involved, include both surnames in this reference. However if more than two authors are involved, you may use 'et al.', an abbreviation of Latin meaning 'and others'. In general you should not use the abbreviation in the full reference at the end of the article, although some journals permit this. If two more or more articles written by the same author in the same year are cited, most journals ask you to add suffixes 'a', 'b' etc in both the text and the reference list.

For example: "We used the HPLC technique outlined by Nondek et al. (1992)." Or, "We used a standard HPLC technique (Nondek et al. 1992)."

To cite an internet source (not recommended for papers in this class), we suggest using the University of Chicago Style:

Harnack, A. and Kleppinger, E. (2001). Citation styles: Using Chicago style to cite and document sources. In *Online! A reference guide to using Internet resources*. Retrieved January 20, 2003 from <http://www.bedfordstmartins.com/online/cite7.html>

Crouse, M. (2002). *Citing electronic information in history papers*. Retrieved January 20, 2003 from <http://cas.memphis.edu/~mcrouse/elcite.html>

We are providing a separate handout with more information on citing internet sources.

If you include in your paper phrases, sentences or paragraphs repeated verbatim from the literature, it is not sufficient to simply cite the source. You must include the material in quotes and you must give the number of the page from which the quote was lifted. For example: "Day (1979: 31) reports a result where '33.3% of the mice used in this experiment were cured by the test drug; 33.3% of the test population were unaffected by the drug and remained in a moribund condition; the third mouse got away'".

Formats vary from journal to journal, so when you are preparing a scientific paper for an assignment, choose a journal in your field of interest and follow its format for the reference list. Be consistent in the use of journal abbreviations.

Appendices

Appendices contain information in greater detail than can be presented in the main body of the paper, but which may be of interest to a few people working specifically in your field. Only appendices referred to in the text should be included.

Constructing tables and figures

We are providing a separate handout creating tables and figures. But the points below provide a good summary of important elements of good tables and figures.

Tables

DO include a caption and column headings that contain enough information for the reader to understand the table without reference to the text. The caption should be at the head of the table.

DO organize the table so that like elements read down, not across.

DO present the data in a table or in the text, but never present the same data in both forms.

DO choose units of measurement so as to avoid the use of an excessive number of digits.

DON'T include tables that are not referred to in the text.

DON'T be tempted to 'dress up' your report by presenting data in the form of tables or figures that could easily be replaced by a sentence or two of text. Whenever a table or columns within a table can be readily put into words, do it.

DON'T include columns of data that contain the same value throughout. If the value is important to the table include it in the caption or as a footnote to the table.

DON'T use vertical lines to separate columns unless absolutely necessary.

Figures

DO include a legend describing the figure. It should be succinct yet provide sufficient information for the reader to interpret the figure without reference to the text. The legend should be below the figure.

DO provide each axis with a brief but informative title (including units of measurement).

DON'T include figures that are not referred to in the text, usually in the text of the results section.

DON'T be tempted to 'dress up' your report by presenting data in the form of figures that could easily be replaced by a sentence or two of text.

DON'T fill the entire page with the graph leaving little room for axis numeration, axis titles and the caption. The entire figure should lie within reasonable margins (say 3 cm margin on the left side, 2 cm margins on the top, bottom and right side of the page).

DON'T extend the axes very far beyond the range of the data. For example, if the data range between 0 and 78, the axis should extend no further than a value of 80.

Adapted from text developed by the Applied Ecology Research Group at the University of Canberra Australia, and prepared with the aid of 'How to Write and Publish a Scientific Paper' by Robert Day (ISI Press, Philadelphia, 1979).

General Writing Hints

Start paragraphs with a topic sentence or a summary statement. Then follow it with supporting statements. This technique makes your writing clearer and easier to follow. Ideally, someone could read the first sentence of each paragraph and still understand the gist of your paper.

To avoid dull writing, use the “active” voice rather than the “passive” voice:

Bad – Marine algae are eaten by sea urchins.

Better – Sea urchins eat marine algae.

Make sure the object to which words like “this” or “it” refer to is clear.

Combine sentences with low information content. This will make your writing more streamlined and less repetitive. But look out for run-on sentences.

Bad – Boersma (1911) studied the diet of penguins. She found they ate fish.

Better – Penguins primarily eat fish (Boersma 1911).

“Data” is plural. “Datum” is singular. Do not use contractions, “folksy” adjectives, or a conversational style in scientific papers.

Do not anthropomorphize. A bee or dandelion does not have the same consciousness and emotional life as your roommate.

Bad – This superweed intends to dominate and conquer the entire Puget Sound region.

Better – This weed is quickly expanding its range in the Puget Sound region.

Write several drafts. Hard editing will make your papers concise.

Look at scientific journals such as Ecology, Auk, and Conservation Biology to see how scientific papers are written. These papers are the standards to which you should aspire and against which your work will be compared.

We recommend you read the following to improve your paper:

McMillan, V.E. 1997. Writing Papers in the Biological Sciences, 2nd Ed. Bedford Books, Boston.

Strunk, W. and E.B. White. 1975. Elements of Style. MacMillan, New York.