Invited Review

Writing a Scientific Paper

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ABSTRACT: Scientific papers are written to a rigid format, composed of 4 sections, which correspond with the stages of the scientific method. This essay describes the relationship of the standard sections of a paper to the stages of the scientific method. Also for discussion will be the timing of the preparation of the paper and the relationship between the experimental protocol and the eventual paper.

Table 1
Sections of a scientific paper.

Stages of the scientific method	Sections of a scientific paper
Identify a problem to be studied	Introduction
State the hypothesis	Introduction
Carry out experiments	Materials and Methods Results
Interpret the results	Discussion Conclusion

Writing scientific papers is a great obstacle for many people, or perhaps for most people. But it is really not all that hard. Papers may be clinical or experimental, but most have in common that they are descriptions of some sort of study. Reviews are different and beyond the scope of this essay. To focus the discussion, I would like to propose a basic rule of writing a scientific paper, which will be explained more fully in the pages that follow.

The Basic Rule: Write the Paper Before You Do the Study!

Now, the basic rule is obviously a paradox. How can you write the paper before you know what the studies have shown? Notice, however, that the basic rule does not say to write the paper *instead* of doing the study. That would be scientific misconduct, and is very heavily frowned upon. No, the basic rule says the opposite. It is certainly true that you cannot finish the paper until the experimental studies have been done. But it is also true that you also cannot start the experimental studies until you have, at some level, already started to write the paper. The basic rule stems from the underlying nature of the scientific process. A paper describing an instance of the scientific process reflects the way that experiments are devised and carried out.

The scientific method (Table 1) can be defined as having 4 stages. First is the identification of a question that can be answered. Second is the formulation of a hypothesis to answer the question. Third, an experiment or series of experiments are designed to either confirm or reject the hypothesis. Fourth, the results are interpreted in terms both of the hypothesis and the original question. As noted below, these correspond to the 4 main sections of a scientific paper.

Most of us learned this in high school. Actually, that is a bit optimistic—some of us did not learn this until college or later. Whenever it was, it subsequently became part of our background knowledge, and we rarely bring it out to look at it closely. In order to understand how to write a scientific paper, one must reexamine the scientific method. A scientific paper is simply a description of the scientific method as applied to a particular example.

Consider how a study is carried out. One first identifies a problem of importance, whether basic science or clinical. That may require some preliminary experimental work or chart reviews, or one may identify the problem by experience. Either way, the investigator must do a thorough literature search to determine what others have found that is relevant to the problem. Only then can one formulate a hypothesis and then design experiments or clinical studies to test that hypothesis. There is simply no getting around this process. To head off to the laboratory or to the medical records department and simply amass a large body of data in the hope that a relevant finding will emerge is not the path to

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0884-5336/07/2206-0636$03.00/0
Nutrition in Clinical Practice 22:636–640, December 2007

a publishable paper. (I know—people do it all the time. And their papers are rejected all the time, too.)

Early in the process, there are no experiments done (or patients studied, or charts reviewed). And yet, one can sit down and write three-quarters of the final paper. The selection of the problem and the statement of the hypothesis form the introduction of the paper. The plan of the experiments to be done, the studies to be carried out, or the data to be obtained from charts form the Materials and Methods section. If you cannot write the Materials and Methods section before doing the study, your planning process is seriously flawed, and you are not ready to do the study yet. Before finishing the paper, you may have to modify it. That is why we call them experiments.

By this time, the paper is halfway written. The Results section has to wait for the studies to be completed. There is no getting around that. But the Discussion section can be written. True, it will have to be modified when the actual results are known. The Discussion section is largely composed of descriptions of what others have found, and that material should already be known from the literature review.

Look at it this way: What are the elements of a grant proposal? They are description of the problem, statement of the hypothesis, review of previous work done, and description of proposed experiments. All are required. And then you must add a section on the significance of the anticipated results. Well, that is the first attempt to write the Discussion section. If it makes you feel better, call it "Significance of Anticipated Results," and change the title to Discussion when you do the final rewrite after the experiments are done.

Writing a Paper: The Details

Let us go through the entire paper. The title comes first, does it not? Actually, I use a draft title and do not finalize the title until after everything else is done. The title should describe the paper accurately, but the exact form is up to the author. Notice that there are 4 types of titles:

1. The description: "Effects of Enteral Glutamine on the Immune Function"
2. The topic/description: "Glutamine Metabolism: The Role of the Liver"
3. The statement: "Arginine Administration Induces Nitric Oxide Synthase"
4. The question: "Does Selenium Deficiency Inhibit Cytokine Production?"

All of these are acceptable; in fact, all 4 types are commonly seen. Try to get specific, however. A paper titled "Glutamine Metabolism" does not communicate very much. And resist any temptation to use purple prose. A title such as "Selenium: Mother Nature's Secret Weapon" belongs in the *Reader's Digest*, not a scientific journal.

The Introduction section truly needs only 2 paragraphs. The introduction is not the place for a detailed review of the literature, although references can be cited when appropriate. Introduction sections are very often too long. In the introduction, the first paragraph discusses what problem or question is being studied and why it was selected for study. The second paragraph discusses the reasoning leading up to the experimental hypothesis. The second paragraph should *always* contain an explicit statement of the hypothesis, either as "the hypothesis of this study is. . . " or "the question this study is designed to answer is. . . . "

The Materials and Methods section is descriptive. The first paragraph should outline the experimental design, or the study design. In a clinical study, it should describe the patient group that has been studied. Subsequent paragraphs should discuss the data collected from the charts (chart reviews), the data collected from patients during the study (clinical studies), and the details of the assays used (basic or clinical studies). Most writers divide the Materials and Methods section up into subsections, like "Experimental Design," "Data Collection," "Cytokine Assays," and so on. The point of using subsections is to make it easy for the reader to focus on the small details of the study. After all, very few people read the Materials and Methods section in its entirety, nor should they. One paragraph, usually the last, should contain a description of the statistical methods used for data analysis. If the statistics are complicated, this is often a separate subsection. In general, and for most short papers, the first paragraph of the Materials and Methods section should contain details of the study design, whereas the last paragraph should contain a description of the statistical analysis.

Somewhere in the Materials and Methods section—usually at or near the end—there should be a subsection, paragraph, or just a couple of sentences describing compliance with guidelines for animal experimentation and approval by the local animal care and use committee. For clinical studies, the equivalent is a statement reporting approval from the local institutional review board. This is a detail, but an important one. If it is not present, most journals will insist it be included before publication.

The Results section should contain data. That is all: no interpretation, no references to other work, just data. Tables and graphs should be used if they make the data clearer or easier to understand. Although it is best to report each piece of data once and only once, it is permissible to use graphs of data that are described in the text or in a table in order to make the findings more comprehensible. The data should always contain statistics, and graphs should be marked with bars for standard deviation or standard error of the mean. Some editors have a preference for one or the other, by the way. I have a slight preference for using standard error, but many editors prefer standard deviation. Either is statisti-

cally valid—they can, after all, be converted to one another—but it is important to note which one you are using. The statistical significance of any differences should be reported, together with the statistical test used to evaluate significance. If more than 1 type of analysis was carried out, it is usually best to divide the Results sections into subsections.

The Discussion section should contain a highly focused review of the relevant literature. Many papers have discussion sections that are far too long. Do not write a review. The reader is not interested in whether you have reviewed a hundred articles. The reader is interested in how previous studies relate to the present study. The most important element of the Discussion section is the interpretation of the results. My preference is that the first paragraph of the Discussion section interpret the findings of the study in terms of the problem and state whether the hypothesis has been proven or rejected. Some authors start the first paragraph with a general discussion of the problem and spend 3 or 4 paragraphs going over the literature before finally delivering the interpretation of their results. Either way works. The last paragraph of the Discussion section should outline the conclusions that have been reached from the study and possibly indicate where the authors intend to go from there. Some authors put this paragraph in its own section, as conclusions.

Finally, it is good manners to put in an acknowledgments section at the end, recognizing contributions of others who were not coauthors, thanking companies for contributing drugs or other materials, and acknowledging financial support from grants or other sources.

Writing the Abstract

Abstract preparation is a minor art form in itself, as even a casual look through the American Society for Parenteral and Enteral Nutrition Clinical Nutrition Week program book will attest. In relation to a paper, abstract writing is a much more formalized process and is quite easy. Many journals use structured abstracts. Usually, scientific abstracts should be no longer than 250 words and should contain: (1) background, (2) methods, (3) results, and (4) conclusions. This corresponds to the 4 sections of the paper: Introduction, Materials and Methods, Results, and Discussion. It should be noted that the MEDLINE abstracts are limited to 250 words. If the abstract of a paper is longer, MEDLINE just cuts it off after the 250th word, which makes for a somewhat incomplete abstract.

To write the abstract, just go through the paper. Some people write a sentence for each paragraph and then edit the excess. Each heading in the abstract contains only 1–3 sentences, so there is no room for elaboration. The background should contain a statement of the hypothesis. Methods should detail the study design and any critical assay techniques. Results should include only the essential points. Conclusions should summarize interpretation of the results and should state whether the hypothesis was supported or rejected. It should be only 2 or 3 sentences. Put in a sentence defining the problem being studied and 1 or 2 sentences summarizing the findings. When a précis is required, remember that it is printed with the title; therefore, do not repeat material in the title. The précis is intended to inform the reader sufficiently for the reader to decide whether he or she wants to read the whole paper.

The Use of Language

Scientific writing is distinctive. It has unusually strict requirements for precision. The difference, for example, between "sterol" and "steroid" might seem trivial to the English literature major but may be vitally important in a scientific paper. However, scientific writing is often boring. That same English major would probably class "scientific literature" as an oxymoron. So if you want people to actually *read* what you write, find the right way to say things precisely, yet still make your writing readable. I have expanded on this elsewhere,[1] and this piece is focused more on form than on style. Nonetheless, it is a good idea to include some observations on style.

There are several conventions in scientific writing. Some are useful, some not. But as with any style of writing, it is best to know the rules. That is so you can tell when you are breaking them.

First is what we might call the "scientific we." It is sort of like the "royal we" used by the Queen of England and other monarchs. I find it amusing that most scientific writers will not use the word *I*. The justification is that most papers are written by multiple authors. Actually, use of the first person plural is very acceptable. It often allows the author to say something more simply and directly than otherwise, although on this topic I might point out that use of the second person in scientific writing is virtually forbidden. You will almost never see it outside of editorials and articles like this.

Use of the third person is universal in scientific papers. There is nothing wrong with this. It is the appropriate person to use for expository prose, after all. It is not the use of the third person *per se* that makes writing tedious. But the third person can be used in either the active voice or the passive voice, and this makes a great difference. The passive voice is the source of much bad writing in the scientific literature.

Authors and editors tend to use the terms "strong" and "weak" when referring to prose, as in, "Hemingway wrote strong prose." What does that mean? It means short sentences, direct expressions, few qualifiers, few or no subordinate clauses, use of the active voice. Although scientific writing pretty much has to contain long words, qualifiers, and

subordinate clauses, all are overused. The passive voice is especially overused.

Use the active voice when possible. "We used the microarray technique to study DNA": direct, strong, an example of use of the first person plural to simplify. Compare this with, "The method that was used to characterize DNA was the microarray technique." The second sentence is passive voice, twice as long, and harder to read. The important words are buried in subordinate clauses; overall, not a good way to go.

One might conclude a study with a sentence such as "Data produced in the course of these experiments demonstrate greatest consistency with the initial hypothesis that an effective agent for the treatment of vitamin D deficiency is cod liver oil." Compare that with "The data support the hypothesis that cod liver oil can effectively treat vitamin D deficiency." There are 15 words instead of 30. There is 1 subordinate clause instead of 5. The meaning is exactly the same.

A clear and direct writing style does more than make the paper readable. It enhances clarity, communicates meaning more completely, and prevents ambiguity. If you find that your sentences are running longer than 20 words, break them into 2 sentences. If important words or concepts are in subordinate clauses, rework the sentence. If you have redundant words, pare them out ruthlessly. An eminent writer once concluded an overly long letter by saying, "I'm sorry this is so long. I didn't have time to shorten it." Take the time. Your papers will read better, and you will get published more often.

It is probably a good idea to have your paper reviewed by someone else. This is especially valuable, by the way, if English is not your native language. But it is a very good idea for everyone. All of us tend to gloss over our own errors. After all, we know what we meant, right? Find a colleague who really likes to be critical. Let him or her have the paper for a week or 2. Your papers will improve greatly. It may be less helpful after you have published your first hundred papers. It is a very good idea before that.

Conclusion

Writing a scientific paper is both easier and harder than most people make it out to be. It is easier because writing the paper is, or should be, an integral part of carrying out the study. The thought processes and intellectual work required to do the study are the same as required to write the paper, which is why the paper should be written concurrently with doing the study. One should never finish a study and then sit down to write the paper. That is doing the whole thing twice.

But it is harder because it requires that the investigator think out in advance what question he or she is trying to answer. As we all know, it is usually easier to do than it is to think. At least, it seems easier. The hardest part about writing a good paper is to get the study itself done correctly. If the study is properly designed, the paper should be easy to write.

Useful Style Books and Reference Guides

This last section discusses several books and references that may be useful in preparing and revising scientific papers. There are quite a number of such books, and my choices are just that: one person's choices. With 1 exception, all of these books have been through multiple editions, which strongly suggests that they have proved useful to writers over 2 or 3 decades. Although there is no guarantee that your local bookstore will have them, all are available through online booksellers.

1. Strunk and White, *The Elements of Style*.[2] This is the classic book on how to write good English papers. The original authors have died, and the work has been updated to better reflect modern usages.

2. The Economist, *Style Guide*.[3] The *Economist* uses outstandingly good English: simple, direct, and precise. This guide is arranged alphabetically by topic and is a very useful book for looking up particular subjects.

3. Iverson et al, eds. *AMA Manual of Style*.[4] This is the *de facto* standard for medical journals. It is not exactly light reading, and it will not teach you how to write well, but it is an essential reference on medical usage.

4. *Stedman's Concise Medical Dictionary for the Health Professions*.[5] There are bigger dictionaries, but this one is big enough and easy to use. If a term is too obscure to be found in Stedman's, perhaps a less obscure term would be a better choice. But be warned: with the broadening vocabulary of molecular biology, genomics, and bioinformatics, even Stedman's is not completely up to date.

5. Huth, *Writing and Publishing in Medicine*.[6] The first version of this book was published in 1982 by a former editor of the *Annals of Internal Medicine*. In several editions and under 2 titles, the little book has guided medical writers ever since.

6. Day and Gastel, *How to Write and Publish a Scientific Paper*.[7] This book has been through 6 editions since 1979. More focused on scientific writing than on medical writing, it makes a good companion to Huth's book.

7. Sheen, *Breathing Life into Medical Writing: A Handbook*.[8] Although old and out of print, Ms. Sheen's book is still available. It was a valiant attempt to help medical writers become clearer and more readable. It is still worthwhile.

References

1. Van Way CW III. On scientific writing. *JPEN J Parenter Enteral Nutr.* 2007;31:449–450.

2. Strunk W Jr, White EB. *The Elements of Style*. 4th ed. New York, NY: Longman; 2000.
3. *The Economist Style Guide*. 9th ed. London, England: Profile Books; 2005.
4. Iverson C, Christiansen S, Flanagin A, et al, eds. *AMA Manual of Style*. 10th ed. New York, NY: Oxford University Press; 2007.
5. Dirckx JH, ed. *Stedman's Concise Medical Dictionary for the Health Professions*. 4th ed. Baltimore, MD: Lippincott, Williams & Wilkins; 2001.
6. Huth EJ. *Writing and Publishing in Medicine*. 3rd ed. Baltimore, MD: Lippincott, Williams & Wilkins; 1999.
7. Day RA, Gastel B. *How to Write and Publish a Scientific Paper*. 6th ed. Westport, CT: Greenwood Press; 2006.
8. Sheen AP. *Breathing Life into Medical Writing: A Handbook*. St. Louis, MO: Mosby; 1982.