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HOW TO READ A SCIENTIFIC PAPER

The main purpose of a scientific paper is to report new results, and to relate these results to previous knowledge in the field. Papers are one of the most important ways that we communicate with one another.

1. ORGANIZATION OF A PAPER

Abstract: A paper begins with a short summary that gives a brief background to the topic, describes the major findings of the paper, and relates these findings to the field of study. This logical order is also that of the paper as a whole.

Introduction: This section presents the background knowledge. The Introduction describes the accepted state of knowledge in a specialized field, and then focuses specifically on a particular aspect, usually describing set of findings that led directly to the work described in the paper. If the authors are testing a hypothesis, the source of that hypothesis is spelled out, and one or more predictions are given. In many papers, one or several major conclusions of the paper are presented at the end of this section, so that the reader knows the major answers to the questions just posed.

Materials and Methods: This section describes the materials used in the experiments and the methods by which the experiments were carried out. In principle, this description should be detailed enough to allow other researchers to replicate the work. In practice, these descriptions are often highly compressed, and they often refer back to previous papers by the authors.

Results: This section describes the experiments and the reasons they were done. In some papers, the results are presented without extensive discussion, which is reserved for the following section. In other papers, results are given, and then they are interpreted, perhaps taken together with other findings not in the paper, so as to give the logical basis for later experiments.

Discussion: This section serves several purposes. First, the data in the paper are interpreted; that is, they are analyzed to show what the authors believe the data show. Any limitations to the interpretations should be acknowledged, and fact should clearly be separated from speculation. Second, the findings of the paper are related to other findings in the field. This serves to show how the findings contribute to knowledge, or correct the errors of previous work.

Figures and Tables: These contain data described in the paper. The figures and tables also have legends, whose purpose is to give details of the particular experiment or experiments shown there.

Variations on the organization of a paper

The formats for two widely read journals, Science and Nature, differ markedly from the above outline. These journals reach a wide audience, and many authors wish to publish in them; accordingly, the space limitations on the papers are severe, and the prose is usually highly compressed. In both journals, there are no discrete sections, except for a short abstract and a reference list. In Science, the abstract is self-contained; in Nature, the abstract also serves as a brief introduction to the paper. Experimental details are usually given either in endnotes (Science) or Figure and Table legends and a short Methods section (Nature). Authors often try to circumvent length limitations by putting as much material as possible in these places. In addition, an increasingly common practice is to put a substantial fraction of the less-important material, and much of the methods, into Supplemental Data that can be accessed online.

2. READING A SCIENTIFIC PAPER

Although it is tempting to read the paper straight through as you would do with most text, it is more efficient to organize the way you read. Start by reading the Title and Abstract and, before going on, review in your mind what you know about the topic. Next, read the Introduction. The amount of time you spend on this section should vary with your knowledge. Skim the Materials and Methods, checking mainly the titles of the sections and subsections. What techniques are they describing? You don't need to read all the details, but you should know what they've written so you can refer back easily. Spend most of your time on the Results, Tables and Figures. Can you see their results in the figures? Does what they say make sense to you? Do the results you can see tie in with what they claim in the abstract? Finish with the Discussion.

Many papers contain shorthand phrases. "(data not shown)" indicates that not all the experimental data are shown, often for reasons of space. This practice is accepted when the authors have documented their competence to do the experiments properly (usually in previous papers). Two others are "unpublished data" and "preliminary data". The former either means that the data are not of publishable quality or that the work is part of a larger story that will one day be published. The latter means different things to different people, but one connotation is that the experiment was done only once.

3. Difficulties in reading a paper

One major problem is that many papers are poorly written. This can be due to a lack of interest in spending time ensuring the prose is clear and logical, or the result of the author being so familiar with the material that it is difficult to step back. This has several consequences for the reader. First, the logical connections are often left out. Instead of saying why an experiment was done, or what ideas were being tested, the experiment is simply described. Second, papers are often cluttered with a great deal of jargon. Third, the authors often do not provide a clear road-map through the paper; side issues and fine points are given equal air time with the main logical thread.

Another major difficulty arises when the reader seeks to understand just what the experiment was. All too often, authors refer back to previous papers; these refer in turn to previous papers in a long chain. Often that chain ends in a paper that describes several methods, and it is unclear which was used. Or the chain ends in a journal with severe space limitations, and the description is so compressed as to be unclear. More often, the descriptions are simply not well written, so that it is ambiguous what was done.

Other difficulties arise when the authors are uncritical about their experiments; if they firmly believe a particular model, they may not be open-minded about other possibilities. These may not be tested experimentally, and may even go unmentioned in the Discussion. Still another, related problem is that many authors do not clearly distinguish between fact and speculation, especially in the Discussion. This makes it difficult for the reader to know how well established are the "facts" under discussion.

One final problem arises from the sociology of science. Many authors are ambitious and wish to publish in trendy journals. As a consequence, they overstate the importance of their findings, or put a speculation into the title in a way that makes it sound like a well-established finding. It's not so bad when the assertive sentence is well-documented, but all too often the assertive sentence is nothing more than a speculation, and the hasty reader may well conclude that the issue is settled when it isn't.

4. Evaluating a paper

a. What questions does the paper address?

Before addressing this question, we need to be aware that research can be of several different types, or a combination of these approaches:

Type of research	**Question asked**
Descriptive	What is there? What do we see?
Comparative	How does it compare to other organisms/sites? Are findings general?
Analytical	How does it work? What is the mechanism?

Descriptive: This research often takes place in the early stages of our understanding of a system. We can't formulate hypotheses about how a system works, or what its interconnections are, until we know what is there.

Comparative: This research often takes place when we are asking how general a finding is. Is it specific to my particular organism, or is it broadly applicable? A typical comparative approach would be comparing the species composition or diversity from one location with that from other locations.

Analytical: This research generally takes place when we know enough to begin formulating hypotheses about how a system works, about how the parts are interconnected, and what the causal connections are. A typical analytical approach would be to devise two (or more) alternative hypotheses about how a system operates, and devise a set of experiments to distinguish among these hypotheses.

b. What are the main conclusions?
For a quick answer to this question, study the Abstract. Here the authors highlight what they think are the key points. However, this may not be completely inclusive as abstracts often have severe space constraints, but it can serve as a starting point. It helps to read the paper with the main question in mind.

c. What evidence supports those conclusions?
Look at the Results section. Be sure you understand the Tables and Figures. Do you agree with the authors' interpretations? Next look at the Discussion. Ideally, it begins with a section of the form "Three lines of evidence provide support for the conclusion that…" Be sure that you understand the relationship between the data (Tables and Figures) and the conclusions.

d. Do the data actually support the conclusions?
If we assume for the moment that the data are believable (see next section), it still might be the case that the data do not actually support the conclusion the authors wish to reach. There are at least two different ways this can happen:

i. The logical connection between the data and the interpretation is not sound
ii. Other interpretations might also be consistent with the data.

One important aspect to look for is whether the authors take multiple approaches, or have multiple lines of evidence to answer a question. Another thing to look for are implicit or hidden assumptions used by the authors in interpreting their data. This can be hard to do, unless you understand the field thoroughly.

e. What is the quality of that evidence?
This is the hardest question to answer, for novices and experts alike. At the same time, it is one of the most important skills to learn as a young scientist. It involves a major reorientation from being a relatively passive consumer of information and ideas to an active producer and critical evaluator of them. This is not easy and takes years to master. Beginning scientists often wonder, "Who am I to question these authorities?" Unfortunately, that's not always the case. Developing your ability to evaluate evidence is one of the hardest and most important aspects of learning to be a critical scientist and reader.

How can you evaluate the evidence? First, you need to understand the methods used in the experiments. Often these are described poorly or not at all. The details are often missing, but more importantly the authors usually assume that the reader has a general knowledge of common methods. Second, you need to know the limitations of the methods. Third, you need to distinguish between what the data show and what the authors say they show. Fourth, you should ask if the proper controls are present. If the controls are missing, it is harder to be confident that the results really show what is happening in the experiment. You should try to develop the habit of asking and locating the controls.

f. Why are the conclusions important?
Do the conclusions make a significant advance in our knowledge? Do they lead to new insights, or even new research directions? Again, answering these questions requires that you understand the field relatively well.

<u>SCIENTIFIC PAPER READING GUIDE</u>

The following exercises will help you focus on key elements of scientific papers. <u>Before</u> you read the paper, spend 5-10 minutes answering the pre-reading questions based on a quick glance of the paper. It doesn't matter if your expectations turn out to be correct or not. What matters is that you have gotten a little bit of information before you begin reading. <u>After</u> reading the paper, take 15-20 minutes to answer the post-reading questions. This will tell you if your expectations were accurate.

By the way, these are the kinds of questions experienced scholars regularly ask themselves, often without thinking about it consciously, when they pick up a new book or article.

<u>PRE-READING QUESTIONS</u>

1. Who is the author? If the article doesn't have biographical material, do a five-minute web search and see what you can learn about her/him. *Write a few sentences about who the author is/was and the context (ie. previous research, department, etc.) in which this person works/worked and writes/wrote.*

2. What does the title make you think this article is about? (List 2 – 4 possibilities) *What's your evidence for this conclusion?*

3. Where is this article from (a book, an academic journal, a magazine, etc.) and what's the title of the source? When was it published?

4. Who do you think the author is/was writing to? What's your evidence for this conclusion?

5. Read the abstract and concluding paragraphs (usually the last one in the discussion). Now, write a paragraph about what you expect this reading to be about and what you think the author's perspective may be. You may list several possibilities. Again, be sure to give the evidence/reasoning that led you to this conclusion.

<u>POST-READING QUESTIONS</u>

1. *What was the major question addressed? How does it relate to general concepts that we have learned in class? What specific hypothesis is being tested?*

2. *What specifically did they do? What was the research system, where was it located, what manipulations were made, how long was the study, what was measured and how did they make their observations and analyze their data?*

3. *What results were obtained in relation to specific questions addressed? Be sure that you understand all the tables and figures – can you see their results in the figures, or are there alternate interpretations?*

4. *How did the results relate to the larger issue being addressed? What did we learn from the study? Were there major problems with the experimental design or results? What are profitable research directions to pursue in the future? What was unclear or confusing to you? If you were to write a short essay question for an exam based on this paper, what would it be?*