How to Read a Scientific Paper - Some Tips for the Mathematician
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Introduction

If you walk into a bookstore at any major airport you're likely to find Crichton's latest techno-thriller, Grisham's latest legal tale, and whatever recent trendy self-help book tops the bestsellers list. You are not likely to find Newton's Principia, anything by Marcus Aurelius, or even any of Einstein's popular works. If you make your way over to the magazine rack you'll find Time, but not Nature, Scientific American, but not Science, and People, but not Physica D. Why? One clue lies in the nature of the skills required to read Newton, Marcus Aurelius, or Einstein, to read Nature, Science, or Physica D, skills that are not generally needed to read Newsweek, Time, or People. These skills are *not* to be found in the particular knowledge of the scientific specialist, but rather are to be found in the general skills of reading possessed by any educated person. Unfortunately, these skills are infrequently taught in our high schools and colleges. It is perfectly possible, even typical, to reach graduate school or beyond and still be lacking many of these basic skills in reading; skills necessary for reading the primary literature in almost every field of knowledge. In this short note I'll outline a reading "recipe" and give some useful tips for developing your skills as a reader of scientific literature. This note is tailored toward the student of mathematics, but should prove useful to anyone who wishes to read scientific articles. Much of this note is based on the ideas set forth in the wonderful book by Van Doren and Adler [1]. Whatever level of skill in reading you currently possess, I strongly suggest making *How to Read a Book* the next book on your reading list.

A Reading Recipe

Whenever you pick up any scientific paper, it is worthwhile breaking your reading of the paper into three steps.

Step One - An Overview
Don't pick up the paper and jump right in! By doing so, you'll be missing a lot of valuable information and you'll lack a frame of reference from which to understand the paper. Your first goal in reading is to answer the question: *What kind of an article is this?* Start by "skimming" the article. What journal published the paper? This alone often gives a large clue as to the type of article you are reading. If the paper is published in the SIAM Journal on Mathematical Analysis you can safely bet that it is not an experimental paper by a biologist. If the paper is published in Science, you are unlikely to find a theorem or a proof in the paper. Next ask yourself, who wrote the paper? Where are they from? While this is not a foolproof indicator of the nature of the paper, it is rare that someone in a chemistry department will publish a paper on problems in theoretical computer science. Now, skim through the paper. How many sections are there in the article? What are their headings? It's often useful to sketch the "backbone" of the paper by abstracting from the section headings. Take a look at the references. Do the authors cite other papers you

know? Books you are familiar with? What fields are represented in the citations? Finally, read the abstract. A well-written abstract should clearly reveal the type of paper you are reading (and more besides).

While it is difficult to order all possible types of scientific papers, it is helpful to list those you are most likely to encounter. This list should serve as a guide, not as an exhaustive classification scheme. Keep in mind that papers often mix together two or more of the types listed below. For example, a paper reporting on an experiment in fluid dynamics may include a mathematical model of the experiment. Nevertheless, the primary classification of each paper you read can usually be determined.

1. Pure Mathematics - If you are reading a paper in this category you are likely to know it from the style. Typically, a paper with a purely mathematical focus will be written in a theorem-proof style.
2. Applied Mathematics - If you are reading a paper in this category it is less likely that you will encounter theorems or proofs. Yet, you can expect a heavy dose of mathematics. The paper will most likely include a description of the application. This category can be further divided into two categories of papers, those that are *application oriented*, and those that are *mathematically oriented*. If this focus is on the application the author's will be attempting to use mathematical tools to answer important questions about a specific application. If the focus is on the mathematics the author's will be attempting to develop mathematical tools that are important in analyzing multiple applied problems.
3. Experimental - An experimental paper reports on the results of an experimental study. You should be aware that each field tends to have their own style of reporting experimental results.
4. Theoretical - A theoretical paper may appear in any field. You can encounter theoretical articles in chemistry, physics, biology, etc. These papers are usually distinguished by the fact that they do not present the result of experiments, but rather attempt to explain experimental work, or predict the results of future experiments. The theoretical description may be very mathematical in nature, it may rely on computer simulations, or it may be more of a descriptive theory, setting forth hypothesis to describe observed data. There can be large overlap with applied mathematical papers. The point of view of the author is often the only feature which distinguishes between an applied mathematical paper and a theoretical paper in a discipline.
5. Review - Review articles rarely report on the results of new research but rather provide a broad, sometimes detailed, overview or summary of work in a given area. Identifying a review article on a topic of interest to you is a very useful way of navigating the literature on a subject. The author of a good review article has already done the work of identifying key papers in a field and has usually read them well enough to present the essential ideas to a general audience.
6. Expository - There are a variety of expository articles that loosely fall into the category of scientific literature. Articles in Scientific American are

representative of one type of expository article. Such articles usually lack technical details, but communicate the essence a field. They differ from review articles in the almost total lack of technical detail and lack of reference to the primary literature. Other types of expository articles include transcripts of talks and articles written for the "general" journals of a scientific society. For example, articles appearing in Physics Today, SIAM Review, or the AMS Notices are often expository in nature.

Step Two - Read for understanding

The second step in reading a scientific paper is to do just that, read it! However, as you read, you should hold in the front of your mind a few ideas.

1. Stay awake! Reading science differs from reading a Grisham thriller in that one cannot let pages pass by with unconscious acceptance. The most important thing to remember when reading science is to *read actively*. This can be an exhausting experience! Do not be surprised if reading a 2-3 page paper takes you 3-4 hours. If you are reading a mathematical paper and working through each proof, it can take even longer. It is useful to read with a pen in hand. Jot notes, underline key phrases, note words you do not know, etc.
2. Come to terms with the author. It is likely that there will be many words in an article that you do not know. Furthermore, since you are reading science, it is likely that these words will have a very precise meaning. You need to decipher this meaning. You can work from context, or you may need to look the words up. Depending on the field of the paper, a specialized dictionary may be necessary. Many such dictionaries are now available online.
3. Identify the author's claims. Why was this paper written? What questions was the author trying to answer? What questions does he claim to have answered? What answers does he propose? What method or methods were used to arrive at these answers? What arguments does the author present to justify his conclusions? This is the meat of the paper. Research is undertaken in order to answer a question. Reports of research present tentative answers. At this point you need to identify those questions and those answers.
4. Identify context. It is also important to understand how the paper you are reading fits into the larger body of scientific literature. Each discipline has its own set of values concerning important questions and its own methods for answering those questions. Identifying these values and methods gives you the context for the article. Taken out of context, most articles will appear puzzling or even meaningless. Viewing them from the point of view of a given discipline gives them meaning.

Step Three - Reflect

Up till now you have been working to understand what the author is saying. *Once you have understood*, now it is time to bring yourself back into the picture. This should be

emphasized, you cannot claim to agree or disagree with an author until you have understood. You should fight any tendency you have to pass early judgment until you have understood what the author is saying, what his arguments are, and the context in which his work belongs. Once you have understood you should:

1. Judge - Each author is making claims and presenting evidence to justify those claims. How convinced are you by the arguments of the author? Your basis for judgment must be based on reason. If you disagree, can you identify where the author has made a mistake in analysis? Can you show that his data is incomplete? If you agree, can you anticipate objections that might be raised and show that these can be addressed?
2. Identify open questions - Rarely will a scientific paper be the final word on a topic. What questions come next? Where did the author leave off? What types of questions could you address that the author has not? You bring a unique perspective and background to this problem. Do you see different facets of the problem than those that have been presented? Can you see where a mathematical model might be of use? Can you see where a clever experiment might put a theory to the test? If you are reading this paper because it relates to a problem that interests you can you know determine the level of relevance?

Closing Comments

As with almost every field of human endeavor, practice makes perfect. The more you read scientific literature and the greater the effort you make to read actively, the easier the process will become. Eventually, the recipe above will become automatic and you won't have to struggle quite as hard. Keep reading!

References

1. Van Doren, C. and M.J. Adler, *How to Read a Book*. 1972, New York: Touchstone. 426.