How to Read a Scientific Paper

Target Audience

This guide is intended for advanced high school students and college undergraduates who are interested in working on independent research projects. Students should have a strong background in science. At minimum, it is recommended that the students have completed two years of high school science courses, although enrollment in advanced high school science classes (like AP Biology, AP Chemistry, or AP Physics), or the equivalent college-level courses, is preferable. Original research can be very rewarding and even fun, but it also takes a huge commitment of time and energy. Having a mentor to help evaluate ideas and provide background information is extremely useful.

Introduction

As you embark on your own original research project, you'll find it necessary to read in-depth scientific literature in your chosen research field. However, this may be the first time you've tried reading a scientific paper and you may find yourself confused about how to proceed. This guide, which is broken into four sections, is intended to help you get started:

- Why bother reading scientific papers? - This section explains what you gain by reading the original scientific literature.
- Two Types of Research Papers Containing Two Types of Information - Here, you will learn what differentiates a review article from a primary research article, and the specific uses for each.
- The Parts and Uses of Primary Research Articles - This section breaks the scientific paper down into its six component parts and explains what kind of information can be found in each part.
- How to Proceed When Reading a Scientific Paper - Learn tips about what you should be doing, physically, as you read the scientific paper to maximize your understanding and get the most out of your time and effort.

Why bother reading scientific papers?

Scientific papers are the heart of the science community; they're one of the major ways scientists communicate their results and ideas to one another. If you're considering doing original scientific research, reading the scientific literature is a *must!* Read the roundtable discussion about Finding an Idea for an Advanced Science Fair Project by students who successfully competed at the top-level

science competitions, and you'll quickly see that scientific papers were vital to those students when it came to both choosing their topics and carrying out their experiments.

Scientific papers contain the most up-to-date information about a field. So if you have a topic you're interested in studying, reading the scientific literature in that field will help you understand what has already been discovered and what questions remain unanswered. The great thing about science is that every time one question is answered, the answer unlocks twice as many new questions. This means that once you've read the literature and know what people have already discovered, you'll probably be able to see what still needs to be done in the field and use that to design your own relevant research project.

Scientific papers also contain information about how experiments were conducted, including how long they took, the equipment and materials necessary, and details about how to physically perform the experiments. This kind of information is critical for figuring out how to do your own experiments, and even whether the project will be physically possible given your equipment constraints.

Two Types of Scientific Papers Containing Two Types of Information

There are two types of scientific papers: review articles and primary research articles. **Review articles** give an overview of the scientific field or topic by summarizing the data and conclusions from many studies. These types of articles are a good starting place for a summary of what has been happening in the field. And they often contain more background information than primary research articles do, which means if at any point you're confused while reading the primary literature, it will help to go back and look at reviews. It is also wise to read several reviews by different authors for a well-rounded perspective of the field; individual authors have their own biases and you want to make sure you're exposed to as many different points of view as possible before you settle on your own conclusions.

Primary research articles contain the original data and conclusions of the researchers who were involved in the experiments. These articles also contain details about how the experiments were done. Or, in the cases of some journals, they might contain web addresses for "supplemental data" found online, which detail the methods used by the authors. In general, primary research articles should be consulted any time you need to get more information about how an experiment was carried out, or if you need to review the original data, which you may want to do in order to base your experiments off their data, or to evaluate for yourself the validity of the authors' conclusions. Primary research articles are also useful for seeing how experts in that scientific field visually represent their data. For example, what types of graphs are common to the field? Are there any specific units that are used? You'll eventually need to know this information to put together a good report or display board to convey your research.

If you're looking at a paper and you're not sure if it is a review or a primary research article, here are a few easy ways to distinguish. First of all, many reviews will be labeled as "review" or "tutorial" on the first page of the article. Also, reviews don't have a "methods" section (although you *can* find entire reviews dedicated to discussing the advances in a specific method or technique). And in a review article, graphs, tables, or figures containing actual data will contain citations in the figure legend to the primary research papers that originally reported the findings.

The Parts and Uses of Primary Research Articles

Primary research articles are typically broken down into six sections: abstract, introduction, materials and methods, results, discussion, and references. A few journals have slightly different formats due to their space constraints or target audience. The most common alteration is to combine the results and discussion parts into a single section. Each part of the paper serves a unique purpose and can help your research project in a different way.

Abstract

The abstract is a summary of the paper. It usually highlights the main question(s) the authors investigated, provides the key results of their experiments, and gives an overview of the authors' conclusions. Reading the abstract will help you decide if the article was what you were looking for, or not, without spending a long time reading the whole paper. Abstracts are usually accessible for free either online at journals' websites or in scientific literature databases.

Introduction

The introduction gives background information about the topic of the paper, and sets out the specific questions to be addressed by the authors. The quantity and thoroughness of the background information will depend on both the authors' proclivities, and the guidelines for that specific journal. Throughout the introduction, there will be citations for previously published articles or reviews that discuss the same topic. Use these citations as recommendations for other articles you can refer to for additional background reading.

Reading the introduction is a test of whether or not you are ready to read the rest of the paper; if the introduction doesn't make sense to you, then the rest of the paper won't either. If you find yourself baffled by the introduction, try going to other sources for information about the topic before you tackle the rest of the paper. Good sources can include a textbook; online tutorials, reviews, or explanations; a review article or earlier primary research article (perhaps one of the ones cited in the introduction); or a mentor. If even after trying all these sources you're still confused, it may be time to consider a new topic.

Materials and Methods

The materials and methods section gives the technical details of how the experiments were carried out, including the types of controls used and where unusual resources (like a bacterial strain or a publicly available data set) were obtained. Reading the methods section is helpful in understanding exactly *what* the authors did. After all, if you don't understand their experiments, it will be impossible to judge the veracity of their results and conclusions! This section also serves as a "how-to" manual if you're interested in carrying out similar experiments, or even in repeating the same experiments as the authors did.

The materials and methods section is most commonly placed directly after the introduction. But if you can't find it there, check the end of the paper, just before the references, or look for a URL within the research article for a "supplementary information" section online.

Results

The results section is the real meat of a primary research article; it contains all the data from the experiments. The figures contain the majority of the data. The accompanying text contains verbal descriptions of the pieces of data the authors feel were most critical. The writing may also put the new data in the context of previous findings. However, often due to space constraints, authors usually do not write text for all their findings and instead, rely on the figures to impart the bulk of the information. So to get the most out of the results section, make sure to spend ample time thoroughly looking at all the graphs, pictures, and tables, and reading their accompanying legends!

Three types of information can be extracted from the results section: data from the experiments, ideas about how to improve the methods, and an understanding of how to represent similar data. Clearly, this is the section of the paper you refer to if you need to know exactly what the researchers found out, particularly if you need data to compare with your own findings, or to use to build your own hypothesis. The results section is also useful for understanding whether the methods of an experiment worked well. For example, a graph of the data might show that although the authors took time points every hour, there was no change at all until five hours into the experiment, and then the change was rapid. By interpreting their graph yourself and making this observation, you would be able to repeat the experiment, with differentially spaced time points, to resolve what actually happened during the fifth hour. And last, but not least, studying the figures will help you understand how to represent your own data in a way that is clear, accurate, and in keeping with the standards in that particular field of science.

Discussion

The discussion section is the authors' opportunity to give you their opinions. It is where they draw conclusions about the results. They may choose to put their results in the context of previous findings and offer theories or new hypotheses that explain the sum body of knowledge in the field. Or the authors may comment on new questions and avenues of exploration that their results give rise to. The purpose of discussion sections in papers is to allow the exchange of ideas between scientists. As such, it is critical to remember that the discussions are the authors' interpretations and not necessarily facts. However, this section is often a good place to get ideas about what kind of research questions are still unanswered in the field and thus, what types of questions you might want your own research project to tackle.

References

Throughout the article, the authors will refer to information from other papers. These citations are all listed in the references section, sometimes referred to as the bibliography. Both review articles (often cited as "reviewed in...") and primary research articles, as well as books or other relevant sources, can be found in the references section. Regardless of the type of source, there will always be enough information (authors, title, journal name, publication date, etc.) for you to find the source at a library or online. This makes the reference section incredibly useful for broadening your own literature search. If you're reading a paragraph in the current paper and want more information on the content, you should always try to find and read the articles cited in that paragraph.

How to Proceed When Reading a Scientific Paper

Whether you're reading a review article or a primary research paper, you're likely to come across vocabulary and concepts with which you're unfamiliar. It's a good idea to have other resources on hand to look up those words and ideas. For example, a scientific dictionary is useful for checking unfamiliar vocabulary, and textbooks are excellent starting places to look up scientific concepts. Internet searches for tutorials or explanations about a specific method or concept can also be useful. And don't forget that people, like mentors and science teachers, can also be great resources when you're stuck.

You're likely to find that reading and understanding a scientific paper is an iterative process: read, look things up, re-read, etc. But if you find that you're spending hours looking up information and not making any progress, then it may be time to consider that this paper is not for you. If that's the case, try going to a more general paper (like a review or textbook entry) about the topic and then returning to the paper after you're more informed. And if that still doesn't help, it may be time to consider changing your topic.

Highlighting important data and making notes directly on a photocopy or printout of the paper can be a good ways to keep track of the information as you move through the paper. Taking notes will help you encapsulate what is important about the paper, and keep you focused on the task. You may even want to make a diagram or sketch in the margins to remind yourself how an experiment was done. These notes also provide a visual key to the pieces of data most relevant to you so that when you need to go back to the paper to remember a detail, it'll be easy for you to find it.

In all cases, start by reading the abstract; read it to make sure the paper is what you were looking for and is worth your time and effort. If the abstract indicates the paper is of interest to you, move on to the introduction. If you're already familiar with the paper's topic, you can just skim the introduction and materials and methods sections to make sure you're truly up-to-date. But if you aren't familiar with the topic, or if skimming reveals terms or concepts you don't understand, you'll need to read the introduction and then the methods section carefully, stopping to consult other resources or cited literature to augment your understanding.

Once you're sure you have a handle on the background information and an idea of how the experiments were performed, you're ready to tackle the results section. The first step is to examine each figure and table. Make sure to read the accompanying figure legend so you know what all the variables are, and refer back to the methods if you're unsure of how the data was collected. Try to analyze and draw your own conclusions from the figures. Then, once you've looked at all the figures, go back and read the results text. Since you've already been through the data on your own, you'll be better able to follow the authors' writing, and to decide if you agree with the conclusions they're making about the data.

Lastly, if you're interested in the authors' interpretations of the results, read the discussion. If you're already very familiar with the topic, you may find that reading the discussion is unnecessary. But for people just entering the field, discussions are a good place to get a glimpse of what the current competing theories and hypotheses are.

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