**Before you begin: some general advice**

Reading a scientific paper is a completely different process than reading an article about science in a blog or newspaper. Not only do you read the sections in a different order than they're presented, but you also have to take notes, read it multiple times, and probably go look up other papers for some of the details. Reading a single paper may take you a very long time at first. Be patient with yourself. The process will go much faster as you gain experience.

Most primary research papers will be divided into the following sections: Abstract, Introduction, Methods, Results, and Conclusions/Interpretations/Discussion. The order will depend on which journal it's published in. Some journals have additional files (called Supplementary Online Information) which contain important details of the research, but are published online instead of in the article itself (make sure you don't skip these files).

Before you begin reading, take note of the authors and their institutional affiliations. Some institutions (e.g. University of Texas) are well-respected; others (e.g. the Discovery Institute) may appear to be legitimate research institutions but are actually agenda-driven. *Tip: google "Discovery Institute" to see why you don't want to use it as a scientific authority on evolutionary theory*.

Also take note of the journal in which it's published. Reputable (biomedical) journals will be indexed by Pubmed. Beware of questionable journals.

As you read, write down **every single word** that you don't understand. You're going to have to look them all up (yes, every one. I know it's a total pain. But you won't understand the paper if you don't understand the vocabulary. Scientific words have extremely precise meanings).

**Step-by-step instructions for reading a primary research article**

**1. Begin by reading the introduction, not the abstract.**

*The abstract is that dense first paragraph at the very beginning of a paper. In fact, that's often the* <u>*only*</u> *part of a paper that many non-scientists read when they're trying to build a scientific argument. (This is a terrible practice—don't do it.). When I'm choosing papers to read, I decide what's relevant to my interests based on a combination of the title and abstract. But when I've got a collection of papers assembled for deep reading, I always read the abstract* <u>*last*</u>*. I do this because abstracts contain a succinct summary of the entire paper, and I'm concerned about inadvertently becoming biased by the authors' interpretation of the results.*

**2. Identify the BIG QUESTION.**

Not "What is this paper about", but "What problem is this entire field trying to solve?"

*This helps you focus on why this research is being done. Look closely for evidence of agenda-motivated research.*

**3. Summarize the background in five sentences or less.**

Here are some questions to guide you:

What work has been done before in this field to answer the BIG QUESTION? What are the limitations of that work? What, according to the authors, needs to be done next?

*The five sentences part is a little arbitrary, but it forces you to be concise and really think about the context of this research. You need to be able to explain why this research has been done in order to understand it.*

**4. Identify the SPECIFIC QUESTION(S)**

What **exactly** are the authors trying to answer with their research? There may be multiple questions, or just one. Write them down.  If it's the kind of research that tests one or more null hypotheses, identify it/them.

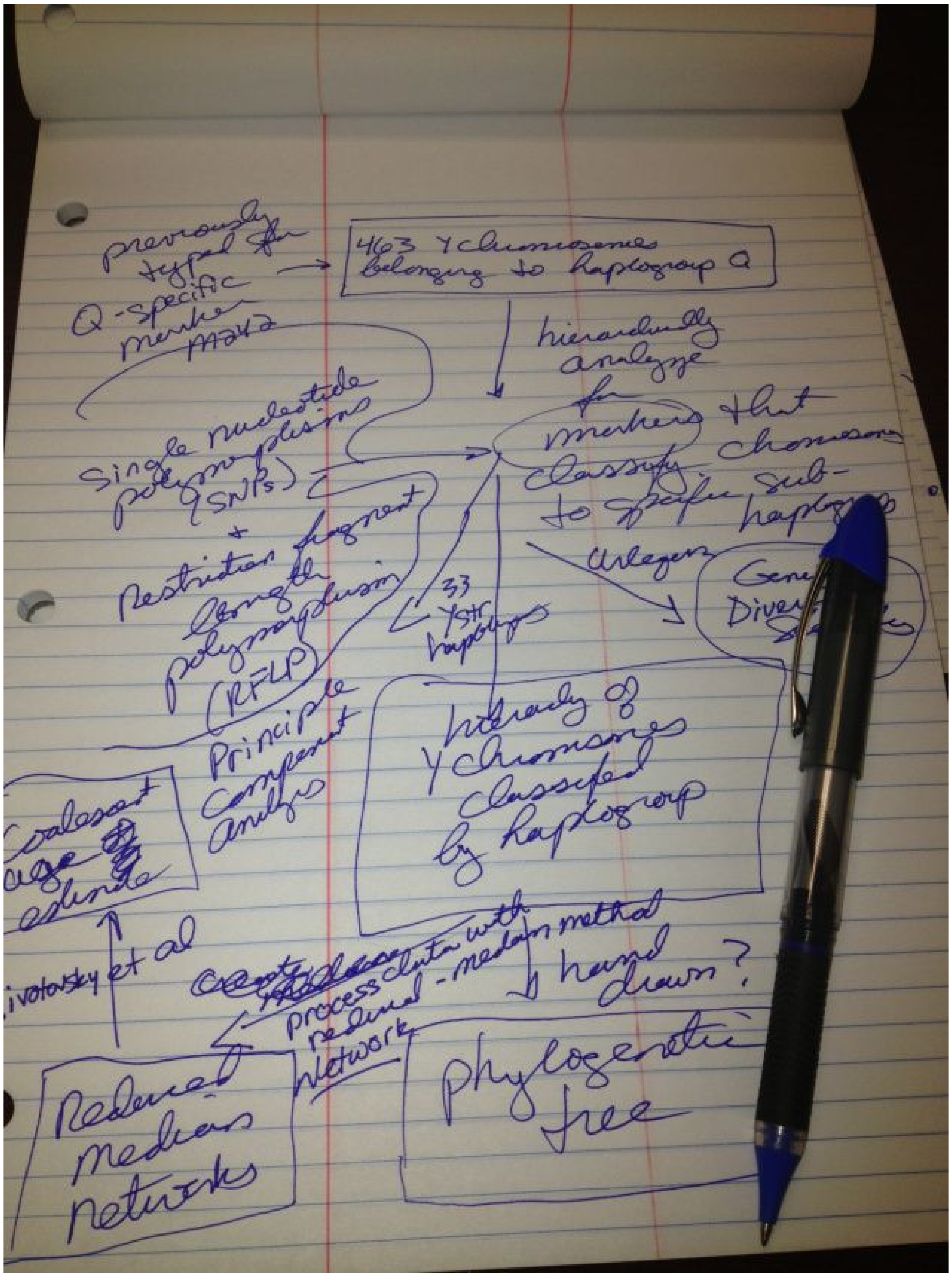
*Not sure what a null hypothesis is? Go read this, then go back to my last post and read one of the papers that I linked to (like this one) and try to identify the null hypotheses in it. Keep in mind that not every paper will test a null hypothesis.*

**5. Identify the approach**

What are the authors going to do to answer the SPECIFIC QUESTION(S)?

**6. Now read the methods section. Draw a diagram for each experiment, showing exactly what the authors did.**

I mean *literally* draw it. Include as much detail as you need to fully understand the work. As an example, here is what I drew to sort out the methods for a paper I read today (Battaglia et al. 2013: "The first peopling of South America: New evidence from Y-chromosome haplogroup Q"). This is much less detail than you'd probably need, because it's a paper in my specialty and I use these methods all the time.  But if you were reading this, and didn't happen to know what "process data with reduced-median method using Network" means, you'd need to look that up.



*You don't need to understand the methods in enough detail to replicate the experiment—that's something reviewers have to do—but you're not ready to move on to the results until you can explain the basics of the methods to someone else.*

**7. Read the results section. Write one or more paragraphs to summarize the results for each experiment, each figure, and each table. Don't yet try to decide what the results *mean*, just write down what they *are*.**

You'll find that, particularly in good papers, the majority of the results are summarized in the figures and tables. Pay careful attention to them! You may also need to go to the Supplementary Online Information file to find some of the results.

*It is at this point where difficulties can arise if statistical tests are employed in the paper and you don't have enough of a background to understand them. I can't teach you stats in this post, but here, here, and here are some basic resources to help you. I STRONGLY advise you to become familiar with them.*

**THINGS TO PAY ATTENTION TO IN THE RESULTS SECTION:**

-Any time the words "significant" or "non-significant" are used. These have precise statistical meanings. Read more about this here.

-If there are graphs, do they have error bars on them? For certain types of studies, a lack of confidence intervals is a major red flag.

-The sample size. Has the study been conducted on 10, or 10,000 people? (For some research purposes, a sample size of 10 is sufficient, but for most studies larger is better).

**8. Do the results answer the SPECIFIC QUESTION(S)? What do you think they mean?**

*Don't move on until you have thought about this. It's okay to change your mind in light of the authors' interpretation—in fact you probably will if you're still a beginner at this kind of analysis—but it's a really good habit to start forming your own interpretations before you read those of others.*

**9. Read the conclusion/discussion/Interpretation section.**

What do the authors think the results mean? Do you agree with them? Can you come up with any alternative way of interpreting them? Do the authors identify any weaknesses in their own study? Do you see any that the authors missed? (Don't assume they're infallible!) What do they propose to do as a next step? Do you agree with that?

**10. Now, go back to the beginning and read the abstract.**

Does it match what the authors said in the paper? Does it fit with your interpretation of the paper?

**11. FINAL STEP: *(Don't neglect doing this)* What do other researchers say about this paper?**

Who are the (acknowledged or self-proclaimed) experts in this particular field? Do they have criticisms of the study that you haven't thought of, or do they generally support it?

*Here's a place where I do recommend you use google! But do it last, so you are better prepared to think critically about what other people say.*

(12. This step may be optional for you, depending on why you're reading a particular paper. But for me, it's critical! I go through the "Literature cited" section to see what other papers the authors cited. This allows me to better identify the important papers in a particular field, see if the authors cited my own papers (KIDDING!....mostly), and find sources of useful ideas or techniques.)

# 10 big questions to dissect science papers

1. What is the central point the authors are trying to prove? Read carefully to determine whether the authors actually get there or fall short and/or over-interpret results.
2. Does it matter how often an experiment is repeated? Generally if you get a specific result once, it could be a mistake. If you get the same result twice, it could be a coincidence. If you get the same result three times, then maybe you have an interesting story.
3. Are there any controls? An experiment is usually only as good as its controls, which should address multiple aspects of the experiment including sensitivity of assays used, what a "positive" result should look like, and what a "negative" result should look like. This allows an experiment to be evaluated by comparing experimental findings to multiple standards.
4. Do they use the best methods available? This brings up several related questions. Check whether they used methods that are qualitative (i.e., is something there or not) versus quantitative (i.e., if it's there, how abundant is it?). Consider whether they use rigorous and complementary approaches such as cellular

lineage-tracing, clonal analysis, and/or functional assays. Do they overly rely on a simple phenotype (i.e., something sort of "looks" like "X," so they call it "X")?

5. Always ask yourself, "What experiment didn't they do that could make the data more convincing?" For example, if a paper shows that a given cell expresses muscle-specific genes that look like muscle cells under the microscope, and that when transplanted into a mouse's damaged muscle integrate and survive, what additional experiment would better convince you that they are in fact bona fide muscle?
6. Did they perform enrichment (i.e., it is mostly this) vs. purification (i.e., it is only this) vs. no idea what they used? If they knock-out/down a gene, is there also a knock-out model? Do they agree or disagree? One would hope that they would produce similar effects. If so, what phenotype does it have? Is the result in an animal model the same as for the cognate human condition? If no, it may actually not be a very useful model of the human disease.
7. Did they increase confidence in the outcome by proving their results in multiple ways? Did they take the time to try to disprove their findings?
8. Is the paper "descriptive/hypothesis generating" or is it "hypothesis-driven" with multiple examples to back up the bottom line?
9. What do other articles say about the topic? If the paper is far afield from what others have published, are its big claims backed up by convincing data? How good is the bibliography? A good research paper should not cite too many review or opinion papers over peer-reviewed, primary research articles from high-impact journals.
10. Have the data been reproduced by other labs? Reproducibility is a key feature of good science and with a brand new finding, only time will tell if others are able to get it to work the same way.