Michael's Guide to Writing a Scientific Paper

Note from Annika: This guide was informally passed around my lab in graduate school. It was written by a highly regarded (and extremely well published) professor. Last I checked on Google Scholar, he's authored or co-authored over 200 articles (more than 10 of these in Science or Nature) and his articles have been cited over 22,000 times.

Disclaimer

This document represents my own personal views and advice on writing a scientific manuscript. It is meant as a helpful guide to starting students who feel overwhelmed with the process of constructing from scratch a paper worthy of submission. Many excellent writers will disagree with much of this document's content, as there is no single perfect way to write a clear and compelling scientific paper. If this guide stimulates debate and discussion among senior authors and students alike, that will be good, as it would indicate that people are at least thinking about the different strategies that can be used to construct a manuscript. Perhaps my most important message is that if you have never written a paper before or struggled with those you have written, it is useful to formally organize a set of guidelines that will, with time, evolve into your own personal style. The following sections describe my own such guidelines, and I hope they will be useful in helping you formulate your own.

Figures

I start with figures because I believe the best way to start the writing process is with figures. Take a blank piece of paper (DO NOT DO THIS ON A COMPUTER!), and sketch cartoons, panel by panel, of every figure in the paper as you initially envision it. The exercise here is not to constraint yourself with whatever preliminary plots and table you might have, but to envision what the perfect paper might look like. What sequence of figures would make the best case? Do you have the data and analysis routines to create such a set of figures? This exercise may send you back to the lab when you realize that one more experiment will make the sequence tighter.

Generally, the first figure is going to be a methods figure that shows the preparation, any new apparatus that you have created, etc. Try to put all the methods description in a single figure, using multiple sub-panels as necessary.

Often it is helpful to use Figure 2 to hold the hand of the reader as you go through the sequence of data analysis that you use in the paper. An annoying problem many papers is that they do not show how raw data turns into the highly derived figures from which the arguments in the paper are made. How many times have you been confused by a histogram, ANOVA table, learning index bar graph or some such thing because you can't see how the raw data were transformed into these high-order displays? Walk the reader carefully through the process in a series of panels. You may need to do this repeatedly throughout the manuscript whenever you introduce a new analysis method.

At the end of the paper, it is a great help to provide a summary diagram – one figure that pictorially displays the basic results of the paper. This is the figure that readers will remember and your colleagues will reprint when they write reviews and textbooks.

Titles

Don't waste time worrying about a title until the paper is almost done. When you are in a good place to think about the title, write down 4 or 5 alternatives. Titles basically range from purposely vague, 'The effects of swamp gas on the mating behavior of feral hogs', to clear statements of the results, 'Specific ratios of swamp gas components elicit sexual receptivity in feral hogs'. Aim for the latter, i.e. a clear statement of your results, but sometimes the results of the paper simply don't justify so strict a claim.

Introductions

At a minimum, introductions have three components, and for a start, try organizing them into three paragraphs. The first section is a general introduction to the topic:

> ‘Evidence from several phyla suggests that the auditory input provided to juveniles by popular music significantly influences the adult food preference (citation). For example, when subjected to 60’s British Wave Psychedelia when young, Bengalese civet cats display a strong preference for field voles (citations). Experiments with synthetic music suggest that it is the rhythmic structure, and not the lyrics, which influence…..

The second section serves as an introduction to your specific experimental system:

> Until recently, there was little evidence that popular music influenced adult food preference in invertebrate animals such as insects. However, Snorkelbut von Winkie recently demonstrated that Velvet Underground baselines could alter the change the food preference of Nepalese diving spiders from caddis flies to dragonfly nymphs…..

The third section explains what you are going to do, how you are going to do it, and gives a brief description of what you found.

> In this paper, we test whether the adult food preference of fruit flies is influenced by popular music played during larval stages. …To perform these experiments, we constructed micro-scaled headphones that could provide auditory input to maggots as they crawled across an agar plate. ….The results suggest that whereas Beatle songs have no influence on adult food preference, flies are exquisitely sensitive to Rolling Stones music, particular cuts from ‘Goat’s Head Soup.

Introduction section can be much longer and more complicated, but it is good to start with this simple narrative – general intro-to-specific intro-to-what you did and what you found. Some authors do not like to hint at the results of the paper in the introduction, as it creates redundancy, but I think some redundancy is good. A simple but helpful rule for the introduction, and every other section for that matter, is that the section should stand by itself if it were the only part of the paper that someone actually read. Each section should have a compelling narrative, and should provide the reader will the basic take-home message of the research.

Methods and Materials

If you are having writing block, it is often helpful to start writing the M&M section – it is the part of a paper with the least emotional baggage. The scientific importance of Methods sections cannot be overstated. Think of how many time you pick up a paper just to learn how an experiment was done. This is particularly important for a technology biased lab, in which students frequently perform studies with novel, home built devices. The best way to organize a Methods section is with subsections, e.g. ‘animals’, ‘electrophysiology’, ‘visual display’, etc.

Results

I am a strong advocate of the notion that the Results section ought to have a strong narrative pull. In structure, you will write a paragraph that explains the result associated with each panel of each figure or each table, in the sequence in which they are presented. They way to provide narrative to a Results section is to explain: 1) what you learned from the last set of experiments and 2) why the drove you to do the next set of experiments:

> ‘The results displayed in Figure 3 demonstrate that sun spiders cannot discriminate among different color m&ms. To test whether they can discriminate Halloween candy based on shape, we repeated our choice task using peanut and plain m&ms.’

Sentences of this type serve as segues among components of what is an otherwise dry part of a paper and make it much easier to read. I think you will find it easier to write as well, as it forces you to organize you results in a proper sequence.

Discussion

Discussion sections seem to be the part of a paper that causes to most stress in first-time authors. It is possible to lower the activation energy by following a rough boilerplate that I believe works for most papers. A good start is to organize the discussion into three parts.

Part one is a paragraph that succinctly describes what you found. Make a list of what you think are the most important results and observation, remind the reader what these are, and give a reference to the figure, panel, or table which demonstrates these points:

> 'By using micro-headphones, we have been able to provide precise auditory stimuli to moving third instar larvae. The results indicate that listening to popular music as juveniles influences the adult food preference of *Drosophila*. The rhythmic structure, and not simply the spectral content, is critical for this effect (Figure 2C). Unlike prior research with head lice, *Drosophila* can discriminate between Beatles and Stones songs, the latter inducing a strong adult preference for papaya (Figure 3B)…..'

The next part of the discussion is a series of sections (each section might be 1-3 paragraphs), each of which addresses an import consequence of the research. A good way to organize this section is to start with subsection headings (this is quite common in JEB papers), 'Importance of rhythmic structure', 'Ecological relevance of pop music influence', 'Relevance of current findings to prior research', ' Neural mechanisms underlying auditory influence'. In the final version you may not need to use subsection headings, but they provide a helpful scaffold for your discussion as you write it. As you flush them out, you will find that some sections really aren't necessary, some may fuse together, some new sections may be necessary.

The final section should be one final restatement of the main result, and its most important consequence. Here is where you might find a place for a summary figure. Many first time writers end their papers with a whimper because they don't make the effort to make one final stab at a good definitive summary. Remember, this is that last text that a reader will swallow as they read your paper. Don't end it on some namby-pamby caveat or less-than-critical subtlety.

Verb Tense

Here's the age old problem – should you write in past tense or present? There is no perfect answer to this, but it is very helpful to devise and maintain a strategy so you don't get strangles by this issue every time you write. My basic rule is that if you are talking about past research and past experiments (even those in your paper) use the past tense. If you are stating a result or claim based on experiments (including yours) then use the present tense. I think it is best to go through this section by section.

The past tense is best for the Introduction, because for the most part you will be discussing past research. However, if a general consensus or model emerged from the research, then describe such in the present, as it represent a current understanding:

> 'Von Winkie **extanded** these results to include holometabolous insects. Collectively, these studies **show** that popular music **influences** adult food preference in a wide range of insects.

For the most part, the past tense works for the Methods and Results sections because you are describing what you did. However, if you provide narrative in the Results section by stating findings, then you may want to switch to present tense:

> 'The results displayed in Figure 3 **demonstrate** that sun spiders cannot **discriminate** among different color m&ms. To test whether they can discriminate Halloween candy based on shape, we **repeated** our choice task using peanut and plain m&ms.'

The Discussion section causes the greatest problems with respect to tense, but try following the same rules as above. Discuss results using the past tense, but as you synthesize the results together into claims, models or hypotheses, switch to the present. Animals and plant are alive, so present tense should be used when describing how they work.

Voice

Scientists seem to be most comfortable using the passive voice. Some of my colleagues even assert that it is the only proper voice to use, because it provides objectivity to the text. I personally think this is nonsense, and believe most professional writers would agree. Good writing is good writing, and any book on expository style (e.g. Shrunk and White) expose the passive voice for what it is – an imprecise construction because it does not clearly identify the subject of an action. Most of the confusion comes from the fact that scientists are uncomfortable using first person construction in the Methods and Results sections,

> 'Animals were placed in small round cages and provided with a choice of m&ms'

Here's my favorite from a paper I read in graduate school,

> 'Calcium ions had there concentrations changed'.

There is nothing wrong with saying that you did the experiments, unless in fact you did not, but in which case you are all the more under an obligation to say who did. After writing half the paper (Methods and Results) in passive voice it is hard to get out of the habit in the Introduction and Discussion where over use of the passive can result in imprecise and uncompelling prose. UI think Strunk and White were correct – start with the 'plain style'. The clearest sentences possess the structure: 'the **subject verbed** the **object**'. The importance of simple, active voice plain style is especially critical in the Discussion section when you are providing mechanistic explanations for the phenomena you have studied.