Scientific Writing: My Approach and Irreverent Opinions

Mark Yeager

Writing is nature's way of letting you know how sloppy your thinking is. (Guindon, San Francisco Chronicle, 3/1/89)

General comments

Scientific writing is much easier than writing fictional prose and poetry because it is so structured and formulaic. Nevertheless, it is still the hardest work we do. If a set of experiments fails, eventually you can give up. However, if you are expected to write a manuscript, there is no turning back. Usually we are under duress to write a manuscript about experiments that are not the focus of our attention. We already know what the answer is, and we want to move on to the next set of experiments. The task of writing requires considerable self-discipline.

The best practice is to prepare the figures and write the paper as the experiments are being performed. You often know what the important, general results are before the final data are collected and processed (just leave XXXs in the text where the numbers go). The best practitioner I know is Nigel Unwin, who would have a binder with dividers for each section of the manuscript. As he would be waiting for the vacuum to equilibrate in the microscope, he would press on with the writing. His prose displays a wonderful economy of words.

The second best practice is to write the first draft at a meeting where the work is first presented. The experiments will be fresh in your mind, and the free time in the afternoons, evenings and on the plane may be sufficient to write a draft. (I recall having all my notebooks and figures with me and dictating the draft of a manuscript on my way home from a meeting in Europe. No doubt I looked like quite the nerd. Fortunately, there was no one else seated in my aisle. But my admin. complained about the loud hissing on the tape, and every so often she said there was this loud voice in the background saying something about seatbelts.) Assistance can also be obtained from your co-authors, who may be attending the same meeting. Team writing is a great way to break procrastination, but it can be terribly inefficient.

Alternatively, the script for a seminar can often be used as a starting draft. However, such a script is usually too “chatty” and will require major revisions. (In order to hear what I say, I often record my seminars with a dictaphone in my pocket or on the podium. It is very humbling to listen to yourself, but it will definitely improve your seminars. And you won’t have to reread your papers if you are asked to talk about something you published a couple years ago.)

The worst is to write a paper after you have departed from the lab in which the work was performed. In this case, the experiments will truly be in jeopardy of never being published. Certainly count on the paper taking at least twice as long to write, and you will have to wedge the writing into all of your new tasks and responsibilities. It is quite likely that your particular project is not absolutely essential to maintain the productivity of the lab you are working in. (Otherwise it would have been written in a timely manner.) Hence, getting your work published is of greatest importance to your own career. As a rule, I try to never accept a post-doc to the lab unless all of their manuscripts from their graduate work are completed.

Scientific writing is especially difficult because we do not particularly enjoy writing, we are not well-trained, and we tend to procrastinate. Scientists are naturally attracted to experimentation and typically choose an educational path with the minimum amount of training in grammar and composition. But do keep in mind that writing is a critical step in science. Even very creative experiments will have a blunted impact if the manuscript is not written well. Maintain the mindset that until your manuscript is peer-reviewed and published, it is as if the experiments were never performed. (Note the alliteration.)

In the same way that you would have no hesitation taking a class in computer programming, you should have no hesitation taking a writing class to improve your skills. Even professional musicians still take lessons and they practice incessantly. The path to writing well is to read excellent writers and to write...and write...and write. If you write manuscripts infrequently, a diary is an excellent venue for practicing your writing. E-mail is an alternative, but the informality of E-mail tends to foster sloppy writing.

Keep your writing concise, dynamic, and simple in construction. As an example of excellent writing, see Stryer's *Biochemistry*. Use the best papers in your field as a template (for example, the style of Steve Harrison's papers have not changed in 25 years).

Convey enthusiasm in your writing so that it isn't listless. This is especially true for grant writing, which is less formal. Even words of emotion can be used judiciously. Convey the human experience of your science. *"Although we were enamored with the simplicity of our purification procedure, we were quite disappointed when the protein was completely denatured under these buffer conditions. Hence, we designed two alternative strategies."* A major part of grantsmanship is your logical display of the sequence of experiments you have planned and how you will proceed depending on the results. (As an aside...in teaching medicine, relating a concept to the care of a particular patient is compelling.)

The cynical viewpoint:

If you plan to be a PI, expect to spend at least 2/3 of your time writing (research manuscripts, grants, review articles, manuscript and grant reviews, letters of recommendation, other letters, memos)....and 2/3 serving on committees and going to meetings. And you may be asked to teach, too. Publications are the currency to funding and promotions....and space. In the future, I suspect we will also be asked to spend more time writing for the lay public in order to justify our work.

And for levity:

I quote others only to express myself better. (Michel de Montaigne, 1533-1592)

When you take stuff from one writer it's called plagiarism, but when you take it from many writers, it's called research. (Wilson Mizner, 1876-1933)

To break writer's block

You can't write well without being enthusiastic about what you're writing about. The goal is to break the procrastination and block in motivation by rekindling your enthusiasm for the experiments and accepting the flaws in your work.

Carve out the time, set a schedule for yourself, and adhere to it mercilessly. Set performance milestones by scheduling meetings with your PI or co-authors.

Break the paper down into sections, paragraphs and then sentences. If you are really at an impasse, just aim to get the ideas down in any form. Don't worry about style, transitions and flow.

Isolate yourself from distractions. For example, don't write in the lab, don't answer the telephone, and don't use a computer with access to the web.

Specific techniques:

1. Give a seminar and record your presentation with a dictaphone.
2. Sit down with all the figures and your notebook, and start rambling into a dictaphone.
3. "Free write" your thoughts; that is, just starting writing whatever comes in to your mind and then ease your thoughts over to the science, even if you just start writing about how difficult it is to write. Ask why is it difficult? Ask what in particular is difficult? Eventually, your writing will drift back to the topic of your experiments.
4. Outline your manuscript and convert to prose. (This seldom works for me. Preparing the outline takes less than an hour. The challenge is converting the outline to prose.)
5. Do something fun and take your laptop with you.
6. Reward yourself. (The easiest time for me to write is on vacation.) A friend of mine was punishing herself for procrastinating on writing an overdue book chapter by not allowing herself to play the piano. (This sentence has way too many prepositional phrases.) Only when playing the piano became her first priority, did she generate the motivation to write the chapter.
7. If you are still blocked, read a paper by someone you admire in your field.
8. If you are still blocked, read the '53 letter by Watson and Crick.
9. And if this doesn't inspire you, read Strunk and White...again.
10. You might also try intimidation: Just imagine that your competitors already have their paper submitted....In fact, they probably do!
11. OK, now if you are still blocked...it is time to think about a career in dentistry...but not medicine or law.

The 4 questions of scientific writing
(Answer the questions, and then you are done. It's easy, really!)

What is the ?	Introduction
What did you do?	Methods
What did you find?	Results
What does it mean?	Discussion

These questions apply to writing abstracts, manuscripts, seminars and grants (just use future tense). Many journals (for example, *The Annals of Internal* M*edicine*, *The New England Journal of Medicine*) explicitly require this format in the abstract. For a grant, the ? you are proposing is presented as the hypothesis to be tested.

The strategy I use is to write the paper so that the reader can easily get the message without actually reading the paper. The title, abstract, section headings, figures and legends should suffice to tell the story. (We all have too little time to read, and it is likely that you will only capture a few minutes, or even seconds, of the reader's attention.)

The method of "divide and conquer"

Break the manuscript down into increments that can be written in an hour or less. Then take a break. If I get stuck on a particular section, I just skip to a different section that is easier to write. In this way, I make dozens of passes through the paper until the draft is completed. The

following order describes the steps I follow for writing the first draft. In general, the sequence moves from what is easiest for me to what is most difficult. After writing the first draft, at least a dozen revisions are usually needed to improve the text. I don't present a draft to my coauthors until I have polished the text to the best of my ability, or I'm too exhausted with the paper to continue. Even then, an additional dozen revisions may be needed to finalize the text....and get everyone to agree on the interpretation. But the task does get easier, the more you write. However, as you proceed through your training and academic career, you are expected to write more papers and grants. A certain flexibility is required because you will be writing several things at the same time. My operational style is to jump from paper to paper and grant to grant as dictated by deadlines and the available time. It's a tough job....but 'ya 'gotta love it! (Just imagine how hard it was before word processors....and typewriters.)

OK, here we go.

1. Decide on the journal (e.g. a brief letter for *Nature* or an opus for *J. Mol. Biol.*) (minutes)

   If you have no competition and a grant deadline isn't looming, aim high.

   If you know your competition is ahead of you, aim for a second tier journal with a rapid publication time. "Pride goes before a fall."

   Being scooped is a bruise to the ego, but I have never been criticized in my grant reviews for being second to publish.

   Quality work endures....at least I hope so.

2. Write several titles (minutes).

   If you are confident of your principal conclusion, an emphatic statement will have the greatest impact:

   "The Cytoplasmic Tail of NSP4, the Intracellular Rotavirus Receptor, Contains Distinct Virus Binding and Coiled Coil Domains". (I like this, but it was still too long.)

   If your work doesn't present a major breakthrough, simply state what you have done:

   "Projection Structure of a Gap Junction Channel at 7Å Resolution".

   Avoid implicit words that weaken the title:

   "A study of...."

   Double titles can add impact, but they also tend to be too long:

   "Supramolecular Organization of Immature and Mature Murine Leukemia Virus Revealed by Electron Cryo-Microscopy: Implications for Retroviral Assembly Mechanisms". The specific technique used (electron cryo-microscopy) can usually be deleted since it can be included as a keyword.

3. Decide on the figures, prepare a mock-up set and write the legends. (1.5 weeks)

   Don't obsess over details in the figures. We all like to prepare figures, and obsessing over the details is an excellent way to procrastinate and avoid writing. If you have spent the last hour deciding on color balance for your map, it is time to get back to the writing.

   Just prepare mock-ups of the figures so that you can carry on with the real work: writing the results and discussion. The text will often guide the final version of the figures, and their preparation will be a nice reward for having hammered out the text.

   Figure order follows the 4 questions: intro (amino acid sequence), data figures (chromatograms, gels, micrographs, tables with statistics), results (correlation plots, maps, cut-away views, close-ups), interpretations (docking of models into maps, mechanistic cartoons)

4. Methods (1 day) *What did you do?*

   I write the methods section first because it's the easiest to write. At least I then don't have to stare at a blank page.

   Use headings for each technique.

(a) Isolation of gap junctions
(b) SDS polyacrylamide gel electrophoresis
(c) Generation of affinity-purified peptide antibodies.
(d) Immunoblot Analysis
(e) Immunofluorescence Microscopy
(f) Thin-section immunoelectron icroscopy
(g) Two-dimensional crystallization
(h) Electron cryo-microscopy
(i) Image analysis

Refer to other papers in the targeted journal using the same techniques to check the writing style.

5. Introduction (3 days) *What is the?*

   The first paragraph should convey the significance of your research (e.g., as it relates to human health).

   Capture your audience. Why is your experiment important? Why should anyone read your paper amongst the 1000s appearing that month?

   "RNA viruses constitute the largest and most diverse group of pathogenic organisms. Of the estimated 17 million deaths that occur each year from all infectious pathogens (1), at least two-thirds may be attributed to these types of viruses."

   Go from the general overview of your topic to the specific.

   Concisely summarize what has gone before to set the stage for describing your experiment:

   "However, to date there has been no direct experimental evidence visualizing transmembrane -helices in gap junctions."

   Conclude with a sentence, summarizing what you did.

   "To further explore the transmembrane architecture of the channel, we analyzed low-dose images of frozen-hydrated, tilted 2D crystals and derived a three-dimensional density map at resolutions of ~7.5Å in the membrane plane and 21Å in the vertical direction."

6. Results (1 week) *What did you find?*

   Use descriptive headings that concisely state the results.

   (a) The truncated receptor domains have different oligomeric states.
   (b) -helical content is correlated with the oligomeric state of the truncated protein.
   (c) Limited proteolysis removes the ICP-binding domain from the cytoplasmic tail.

   Decide on the order of the figures and then write a paragraph describing each one.

   Move from the obvious results to the important results.

   We always try to push our data to the limit. You may want to include but not emphasize results at the edge of significance.

   Depending on your confidence in the results, use a graded set of qualifiers: proves, indicates, suggests, may suggest, appears to suggest (at this point you'd better do some more experiments).

   Don't include so much detail that the impact of the important results is diluted by the minutiae.

   Consider moving details to the figure legends or as a footnote in the citations to not interrupt the pace of the text.

7. Discussion (2 weeks) *What does it mean?*

   Use descriptive headings that concisely summarize the interpretation of the results.

   (a) Icosahedral capsid structure of RYMV and SCPMV

(b) Comparison with other T = 3 plant viruses
(b) Ordered genomic RNA in sobemoviruses
(c) Compact and expanded forms of plant viruses
(d) Functional implications

We all know that this is the hardest section to write, but it is also the most important.

While you are still doing the experiments, think about the meaning of your results in your free time. For instance, while waiting in the grocery line, click through your figures in your mind and ask what the important messages are.

Sometimes the best ideas you have about your work will come when you are not working at all.

8. With the trend toward telegraphic manuscripts, a section on Conclusions is usually not necessary.
9. References (1 day)

   If you are familiar with the literature, the references can be inserted as you are writing.

   Select references that are the best to support the point you are making.

   Don't rely on PubMed for citations. The error rate is at least 10%, especially since special characters are never used.
10. Cover letter (minutes)

    The first paragraph is standard. "Please find enclosed a manuscript entitled "xxx" by "xxx" that we would like you to consider for publication as an "article, letter" in "journal". Included with x copies of the manuscript is a list of suggested referees that are experts in "your field".

    The second paragraph has to enthusiastically and concisely state why your paper "is of general interest to the readership" of the journal. At this point you have labored over the text, and key sentences from the abstract and text can often be lifted and used in this paragraph.

    Suggested referees. Like every endeavor involving humans, science is unfortunately political, and you should suggest referees that appreciate your work.
11. Referees reports (weeks)

    You may think the referee was asleep when he read your paper (or grant) and completely missed the point, but never be arrogant in your replies. Actually, your grant may have put him to sleep.

    Some of the minor criticisms may simply be comments and not require a modification of the text.

    It is likely that no one will ever read your paper more thoroughly than the referees.
12. Page proofs (days)

    Expect your page proofs to arrive just before an important meeting or grant deadline. Editors expect page proofs returned within 24 hours. I have never been able to accomplish this.

    It seems that I always miss some mistakes, so I find it particularly difficult to correct page proofs. Insist that all your co-authors review the proofs.

    Most editorial errors are in the citations. I stack up all the references in order and march through them one by one.

    I compare a hard copy of the text and figures with the page proofs....word for word.

    I also revise the text to conform with the final version that will be published.

    Only when the page proofs are corrected and returned, can you truly say that the manuscript is finished.

Rhetoric

Use a spelling and grammar checker. Don't be upset with all the dings for using passive voice.

Check for incomplete sentences, subject/verb agreement, uniformity of tense, comma splices, run-on sentences, clauses properly modifying their objects, mistakes with "that" and "which", dangling participles.

"Lying on top of the intestine, you can perhaps make out a thin transparent membrane."

Try to only use a maximum of two introductory prepositional phrases and a couple modifying clauses. Again, appreciate the simplicity and beauty of the sentences in Stryer's *Biochemistry*.

If you are having trouble writing a sentence, diagram the sentence to figure it out:

subject|verb|object||conjunction||subject|verb|object

\preposition \dependent clause

\object of the preposition

Check that each paragraph is a self-contained unit with a meaning that is explicitly stated or is obvious.

The best writing has smooth transitions between ideas. Transitions are the mortar that holds the bricks of your thoughts together. (Is this a simile or metaphor?) They distinguish good from excellent writing.

"Secondary structure analysis of the truncated receptor proteins suggests that the amino-terminal region of the cytoplasmic domain assumes a highly ordered -helical conformation, whereas the carboxy-terminal region has a high proportion of random and conformations. We reasoned that such a conformation might render the carboxy-terminal region sensitive to proteolytic enzymes. We therefore used trypsin digestion to further probe the conformation of C90 (Figure 8)."

Logic and Boolean algebra

Associations are not necessarily causally related (but they may be).

Street crime and the sale of ice cream are strongly correlated, but they're not causally related.

Check for correct use of the converse: If *A* implies *B*, then *B* does not imply *A* (but it might).

If the light is green, then I can go through the intersection.

If I am going through the intersection, then the light is green.

Check for correct use of contrapositives: If *A* implies *B*, then *not B* always implies *not A*.

If I am a man, then I have a Y chromosome.

If I do not have a Y chromosome, then I am not a man.

Check for correct use of syllogisms: If *A* implies *B* and *B* implies *C*, then *A* implies *C*.

I am the son of my father.

My father is part Swedish.

Therefore, I am part Swedish.....I mean Sveeedish.

Some disconnected comments

The title, abstract, cover letter and your reputation are the most important factors influencing whether your paper will be reviewed for publication.

or

The most important factors that influence whether your paper will be reviewed for publication are the title, abstract, cover letter, and your reputation based on your previous work.

And more grammar..."That" is the write (Sorry, I had to use a homonym. I mean right.) word here instead of "which" because the sentence has no meaning if the phrase is deleted. The most important factors are the title, abstract and cover letter. Use "which" (preceded by a comma) when the clause can be deleted without losing meaning. Such clauses just provide embellishment for the sentence. For instance, "Convey enthusiasm in your writing so that it isn't listless. This is especially true for grant writing*, which is less formal*."

The path to a manuscript usually takes months and often takes years. Much of the work will have been done (future perfect tense) by the time you start writing the manuscript (for example, figure preparation and presentations at meetings). A typical paper should certainly take no more than 4-6 weeks to write and can often be completed in days (assuming that you are familiar with the literature in your field and have no other tasks at hand).

The challenges are (1) generating the motivation to write when your interest has already shifted to other experiments (....or your next job) and (2) finding the time to write.

Remember that the experiments are not done until they are published...and your letter of recommendation will be much stronger if you leave the lab with all your papers published or in press! (This is a run-on sentence for which a grade of F was given in my 9th grade English class. Two independent clauses connected by a conjunction with no comma....this last phrase is an incomplete sentence because there is no verb...also an F).

And in conclusion

"... the basics of good writing. How good? Let me count the ways as revealed by the touchstone of Strunk and White's Elements of Style. The design is suitable, the voice active, the language definite, specific and concrete. Without a single needless word, fancy expression, extravagant figure of speech or debilitating qualifier, it is neither overwritten nor overstated. Unimpeded by adjectives and adverbs, it is written clearly in a natural way in straightforward, vigorous sentences animated by nouns and verbs." (David Jacobs, Kansas City Star, 12/20/87)

So it goes that none of us will have the impact of Kepler, Descartes or Rosalind Franklin, and a few decades from now, it won't matter anyway. My hope is just to contribute a few scholarly grains of sand on the beach of scientific knowledge. The practical goal is to simply publish quality work at a frequency to stay funded, so that we can continue to do the science we love.

References

R.A. Day, *How to Write & Publish a Scientific Paper* (Oryx Press, Phoenix, AZ, 1994).

R.A. Day, *Scientific English: A Guide for Scientists and Other Professionals* (Oryx Press, Phoenix, AZ, 1995).

K.E. Gordon, *The New Well-Tempered Sentence* (Ticknor & Fields, New York, 1993).

D. Hacker, *A Writer's Reference* (St. Martin's Press, New York, 1992).

C. Hawkins, M. Sorgi, *Research: How to Plan, Speak and Write About It* (Springer-Verlag, Berlin, 1985).

M.J. Katz, *Elements of the Scientific Paper* (Yale University Press, New Haven, CT, 1985).

T.E. Ogden, *Research Proposals: A Guide to Success* (Raven Press, New York, 1991).

L. Reif-Lehrer, *Writing a Successful Grant Application* (Jones and Bartlett Publishers, Boston, 1989).

W. Strunk, E.B. White, *The Elements of Style* (MacMillan Publishing Co., Inc., New York, 1979).

S.F. Trelease, *How to Write Scientific and Technical Papers* (M.I.T. Press, Cambridge, MA, 1958).

Web sites:

Using any web browser, the query "scientific writing" will generate all sorts of good web sites.
http://www.ag.iastate.edu/aginfo/checklist.html
http://www.lingo.ntnu.no/techeng/
http://www.reed.edu/~mgeselbr/Chem212/Writing.html
http://www.srh.noaa.gov/ftproot/ssd/html/writetip.html
http://www.an.psu.edu/jxm57/sciwrit.html
http://courses.lib.odu.edu/engl/jdavis/131description.html