CONTRIBUTIONS

Commentary

Scientific Writing And Publishing—A Guide For Students

Publication is central to the advancement of science—peer-reviewed journals provide access to information that researchers and decision makers can put to use. However, little attention is devoted to instructing students and other early-career writers on strategies for writing and publishing their research. Many authors have provided valuable insights into writing style and the effective communication of ideas (e.g., Mack 1986, Woodford 1986, Day 1998). Rather than revisiting these topics in detail, we focus on the nuts and bolts of organizing, writing, and publishing hard-earned scientific results with the goal of achieving maximum scientific impact. We provide this advice from the combined perspectives of a recent Ph.D recipient (Harley), a current associate editor of *Ecology* and *Ecological Monographs* (Hixon), and a past associate editor of *Limnology and Oceanography* and current contributing editor for *Marine Ecology Progress Series* (Levin). We present this information in the sequence in which a writer would typically proceed, from the identification of main ideas through the final submission of a revised manuscript. Please note, however, that every writer is different and journal guidelines are idiosyncratic, so our advice may not be suitable for everyone and every situation.

Before writing

Several issues should be addressed before any actual writing occurs. Most importantly, the author must establish one or at most two main points that he or she would like to convey in the paper. Any more than this, and the main message is likely to be lost, or worse yet, the paper may become so convoluted that it is never read. At this stage, authors may also be faced with a decision of how much data to include. The SLOSS (single large or several small) debate familiar to reserve designers comes into play in the scientific publication process as well. Given a large body of data, a researcher must decide whether to include a lot of information in a single paper, or divide the data into several smaller contributions. There are advantages and disadvantages to each approach. Ideally, a manuscript should contain enough information that the story is complete, but not such a variety of detail that the main focus is lost. To be avoided is the LPU (Least Publishable Unit) approach that unnecessarily clutters scientific literature.

Once the general content of the manuscript has been established, the identity and sequence of authors can be determined. The first author is assumed to have done most of the writing and to have had the primary intellectual contribution. Although there is variability among and within disciplines as to how many additional authors are included on a paper, secondary authorship typically encompasses individuals who have contributed to the planning and execution of the research, the analysis and interpretation of the data, and/or the writing itself. Galindo-Leal (1996) provides a summary of authorship issues and the degree of contribution that should be expected of an author.

A final piece of the puzzle that must fall into place before serious writing begins is the selection of the desired audience and the appropriate journal to reach that audience. This decision will determine the overall approach taken to introduce the ideas under study and to discuss the implications of the research. It will also affect the length and format of the manuscript, the number and nature of the figures and tables, etc.

Knowing these details in advance makes the writing process much more efficient. Other considerations in the choice of a particular journal are its readership (general vs. specialized), the extent of its distribution, the length of papers considered, the time to publication, and likelihood that a manuscript will be accepted (an issue to which we will return below).

The first draft

It is a surprise to some first-time writers that the components of scientific papers are not most easily written in the order in which they appear in print (e.g., Title, Abstract, Introduction, Methods, Results, Discussion). The organization of the printed text reflects the scientific method, whereby hypotheses are formulated, observations and experiments are conducted, data are generated, and results are interpreted. However, when writing a manuscript, the author already has "the answer" or main idea(s) in hand and must decide how best to convey this information to the reader. Therefore, rather than writing the sections of the manuscript in the order in which they will eventually be presented, it is helpful to write the sections in order of increasing constraints. The manuscript as a whole is largely guided by the available data; it is therefore useful to articulate the objectives of the paper as primary questions or hypotheses, and then organize figures and tables around these at the outset. The *Results* section then follows fairly directly from the presentation of the data in the figures and tables. Once the *Results* have been written, it will become clear what information needs to be included in the materials and methods. The information included in the *Results* also constrains the interpretations presented in the discussion as well as the background information that is pertinent to the *Introduction*. Only when the main body of the text has been written will the true nature of the paper be revealed; thus, the abstract and title should be written last. Below, we flesh out some of the details of writing the various sections of a scientific paper.

Figures, tables, and the Results section

Figures and tables are used to support the main point(s) of the manuscript. Having them organized from the beginning will guide the writing of the text. Needless to say, the figures should be as clear and illustrative as possible (Selby 1976, Tufte 1983). Furthermore, because many readers will only take the time to skim an abstract and glance at the figures and tables, these illustrative tools should be self-contained, with all relevant information included in the captions or footnotes. The text of the results follows directly from the data presented, and does not include finer points of interpretation. However, when certain tests or experiments yield nonsignificant results, it may be convenient to limit the presentation of these to text without supporting figures, unless negative results provide a major conclusion (in which case the power of the statistical analyses becomes an important issue). Note that some journals provide for supplemental data and related information to be published online (e.g., *Ecological Archives* for ESA journals).

Materials and methods section

The content of this section refers to, and is therefore determined by, the information presented in the *Results*, figures, and tables. There should be sufficient detail, both methodologically and statistically, for others to repeat the work. The *Methods* section also allows the reader to put the work into its environmental context. Thus information on the location of field sites, the time at which samples were collected, and environmental parameters for laboratory experiments all merit inclusion. However, the temptation to include too much information (e.g., overly detailed descriptions of the study site or study organisms) should be avoided.

Discussion section

The *Discussion* section is a return to the original objectives and hypotheses. Rather than reiterating the results, the *Discussion* serves to interpret the results and place them in a broader context by citing and discussing related studies. The discussion also provides an opportunity to present some of the implications of the work (e.g., direct applications, implications for other fields). Although new hypotheses suggested by the data may be presented, the discussion should not include extensive speculation that is unsupported by

the data or the literature.

Introduction section

The *Introduction* serves to highlight previous advances on similar topics and therefore to set the rest of the paper in its scientific context. Once the *Results* and *Discussion* have been written (i.e., once the data have been presented and interpreted), it is easier to determine what background information will improve the reader's understanding of the scientific context of the reported research.

Abstract, keywords, and title

Although these components appear at the beginning of the paper, they are most appropriately written last. The abstract is the most important section of the paper because many people limit most of their reading to abstracts, saving in-depth reading for specific projects. This trend is increasing, thanks to online computer searches, which readily provide abstracts, though full copies of the papers may not be available. Thus, it is crucial that the *Abstract* both summarize the key findings of the paper and clearly articulate what is novel and important about the work. The key words should be chosen carefully, because electronic database keyword searches are one of the primary ways people search for information. The title should be concise, informative, and as brief as possible.

Acknowledgments section

The *Acknowledgments* can be written at any time, and this section often provides a welcome break from the writing of more labor-intensive parts of the manuscript. Obvious candidates for acknowledgments are granting agencies and those individuals who substantially improved the research at any stage (from providing access to equipment or field sites to revising the manuscript). There are often individuals outside of science that merit an acknowledgment (e.g., beleaguered spouses, search-and-rescue personnel, bail bondsmen, or pets). Although this section should be concise, it never hurts to make the acknowledgments as generous as possible.

For those who get stuck

Writing can be a frustrating process, particularly for novice authors. Many graduate students suffer considerably as they attempt to write their thesis work. We offer two lines of advice to ease the pain of writing. First, it is quite helpful to work from an outline. If the outline is sufficiently detailed, the writing process consists of expanding each bullet point into a paragraph. This makes the manuscript seem like a much more manageable animal. Second, many people have trouble writing from an outline, or even writing the outline itself. To them, we relay the sage advice of an anonymous neuroscientist/musician: (1) write drunk, and (2) edit sober. Although this strategy was developed for writing rock and roll lyrics, the basic philosophy holds for science writing as well (with or without the consumption of alcohol). If the author is willing to write wildly, knowing full well that most of the material is of poor quality, the production of a draft of any quality whatsoever is often the turning point in the writing process.

The second through final drafts

Once the first draft has been assembled into a readable form, it is extremely important to seek outside critique. Generally speaking, it is very useful for authors to think like a peer referee throughout the writing process, and anticipate the questions that reviewers may raise. (Kuyper [1991] provides a superb list of such important questions.) However, authors are often so involved in the work itself that they may not recognize important gaps in the manuscript. Comments from an advisor and from others both inside and outside of the author's home department can vastly improve a manuscript.

This leads to the issue of how many drafts a paper should go through before it is submitted. One of the most difficult things for a first-time writer to accept is that a paper can *always* be a little bit better. Nevertheless, it is important to be willing to submit a paper even though it is not 100% perfect (especially given that perfection is unattainable). The reasons for this are illustrated in Fig. 1. At a certain stage, authors' efforts will reach a point of diminishing returns. Thus, in the time it would take to improve a manuscript from 98% perfect to 99% perfect, the author(s) could write

a second 98% perfect manuscript in its entirety. In our example, if 95% perfect is the cut-off for submission, then the authors could write and submit three papers in the time it would take to write a single 99% perfect manuscript. The sacrifice of perfection has obvious limits; if submitted papers are of insufficient quality, they will not be accepted. However, the "perfect paper" does not exist, and all papers (even those thought to be very nearly perfect) will need to be revised to some extent following the review process.

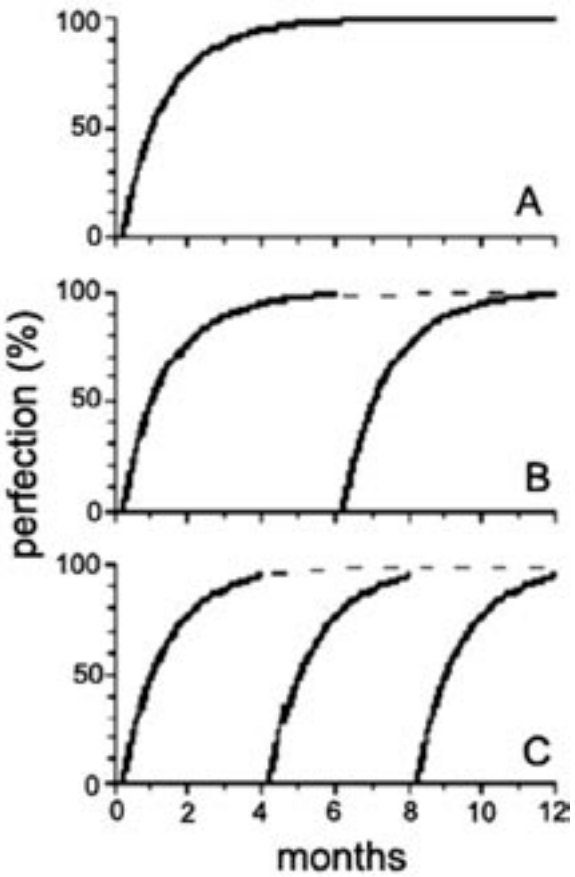

Fig. 1. Manuscript quality through time. (A) Even after 12 months of writing, the paper is only 99% perfect and still improving by small increments. (B) If manuscripts are submitted when 98% perfect, two writing projects can be completed (solid lines) in the time it would take to reach 99% perfection on a single manuscript (dashed line). (C) As above, only 95% perfection is now the cutoff for submission, and three manuscripts are completed. Note that these curves are asymptotic; 100% perfection is never attained.

Submission

Before submission, authors must check the journal format carefully. Failure to follow the journal's guidelines can lead to rejection without review. It is also important that the lead author ensures that all authors have had a chance to read and comment on the final version of the manuscript. Student authors who are still in school should also give their advisor and committee members an opportunity to read the manuscript.

Manuscript submissions are accompanied by a cover letter to the editor. This letter briefly describes the manuscript's topic and its importance. Often, journals will request the names of potential reviewers and their contact information. This is a valuable opportunity to steer the review process toward reviewers who are well qualified to review the paper and are likely to be receptive to the manuscript (e.g., those that are cited in a favorable light). Journals often offer guidelines regarding the content of submission letters. Use them.

The editorial decision

At this stage, it is important for authors to be able to set aside their egos. Manuscripts will be returned with a wide variety of criticisms, all of which (one hopes) are designed to improve the quality of the contribution. Everyone gets hammered by reviewers every now and then, so early career writers should neither despair nor explode when, for example, a reviewer states that the paper "does not provide compelling evidence of anything" (as quoted from a review recently received by one of us).

No papers are published exactly as they are submitted. Comments from reviewers and editors typically range from accepted pending minor revisions to rejected without an invitation for resubmission. If the paper is accepted, the authors should carefully follow any instructions provided by the editor. If revisions have been suggested, these should be incorporated unless the author has very good reasons for not doing so (e.g., the suggested change was based on a misinterpretation of the results). When the manuscript is returned to the editor, it should be accompanied by a

letter that describes and justifies any changes (or lack thereof) made to the manuscript.

If a paper is rejected, authors should first allow the emotional shock of the rejection to subside before taking any action. Then they must decide where (and whether) to resubmit the paper. Often, a paper can be resubmitted to the same journal, provided that substantial revisions have been made and the authors can make a compelling (and polite) argument that the initial rejection was unwarranted. More typically, the rejected paper is revised and sent elsewhere. Because these revisions consume time and effort, it is not in the best interests of the author to have a paper rejected from several journals. This is why the choice of journal is such an important one. On the one hand, scientists who never submit to *Science* or *Nature* will never publish a paper in these high-impact journals. On the other hand, authors who submit everything to top-tier journals regardless of the quality or scope of the manuscript will waste much of their time revising and resubmitting their work—time which could be spent more productively, for example, by writing additional manuscripts (see Fig. 1). It is advisable to have a priority list of journals in mind. If an early-career author is unsure which journals will likely consider his or her work, more senior colleagues can aid in this decision process.

Conclusions

Scientific publication is very important. Publication is often necessary for advancement within the sciences. More significantly, publication is necessary for the research to make an impact. Only when scientists have a document upon which they can elaborate, and decision makers have a document to which they can refer, does the science actually "count." From the standpoint of both the advancement and the application of science, unpublished data effectively do not exist.

Given that writing and publishing are important aspects of the scientific process, we stress that authors should seek to maximize their total impact. For example, the willingness to submit a paper even though it could be a tiny bit better will allow a researcher to devote the time saved to additional research or writing projects. Likewise, not all data should be published. If the importance of the main idea or the quality of the dataset is low, it may be more productive to abandon a project (even if considerable effort has already been invested) and use the time saved to embark on a new project. If the ultimate goal of a scientist is to make an impact on his or her field or on society as a whole, then the intelligent organization and publication of his or her results and ideas can greatly improve the magnitude of that impact.

Acknowledgments

The ideas presented here emerged from a student-sponsored workshop at the 2003 annual meeting of the Western Society of Naturalists. We sincerely thank the graduate student committee, Bonnie Becker, Aimee Bullard, Brian Kinlan, Chris Krenz, Amber Mace, and Michael O'Donnell, for organizing the workshop and inviting us to participate.

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