Guide to Writing an Effective Research Paper

Edited by Bill Menke and Dallas Abbott for the Intern Program, July 20, 2019

The basic elements of the Research Paper are:

Title
Author(s) and affiliations
Abstract
Introduction
Methods
Results
Discussion
Conclusions
Recommendations
Acknowledgements
Bibliography
In addition, your Research Paper May Include
Figures
Table
Appendix

Description of each element:

Title: The title should be just one or two lines long and chosen to give prospective readers a good idea about what the paper is about. Some titles just refer to the type of study being undertaken, other hint at the major finding.

Author(s) and affiliations. You should settle upon a consistent way of writing your name, and consistently use it throughout your career, so that a person who reads and likes your most recent papers can easily spot your next.

The author list should have your name first, since you are the lead author of your Research Paper. Collaborators, such as your Intern Advisor should come afterward. Be sure to ask collaborators' permission before including them as authors, and be sure to write their name in whatever standard way they use.

You should state your affiliation this way " name of your undergraduate institution when you applied to the intern program". For example," Housatonic Community College". If you want to add a second affiliation of "Lamont Doherty Earth Observatory of Columbia University", you can do so.

A variety of formats are in use for the author list and affiliations. You should be guided by the format used in the journal that you most-frequently relied upon during your research. This one is pretty common and is preferred for your paper and your final abstract:

Name[1,2], Name[2], Name[2] and Name[3]
[1]Housatonic Community College, Bridgeport Connecticut
[2]Lamont-Doherty Earth Observatory of Columbia University, Palisades New York
[3]University of Oregon, Eugene Oregon

Abstract: The abstract structure generally follows that of the overall paper, with sections corresponding to aspects of the introduction, methods, results and discussion. Abstracts are short, but writing them is deceivingly hard, as they need to be packed with a lot of information. Because the abstract is the first thing a person reads on your paper, a good abstract sets you up for success, but a bad abstract will put the reader off, not provide enough information on your study, and generally give the reader a bad impression. Many successful abstracts have these parts: (1 sentence) Overview of problem, reference to broader question being investigated. Should be short and relatively interesting and punchy; (1 sentence) A focused overview of what is unknown, providing context for the study and potentially including the aims, goals or hypothesis; (1-3 sentences) The methods you undertook to address the problem, in enough detail to give the reader a general idea of what you did, but not in so much detail that the abstract becomes long and cumbersome; (2-4 sentences). The general results and outcomes, stating the major, significant results; (1-2 sentences) The most important discussion point; and (1 last sentence). The broader implications and importance of your results, which should tie back in to the broader problem stated at the start of the abstract.

Introduction. You can't write a good introduction until you know what the body of the paper says. Consider writing the introductory section(s) after you have completed the rest of the paper, rather than before.

Be sure to include a hook at the beginning of the introduction. This is a statement of something sufficiently interesting to motivate your reader to read the rest of the paper, it is an important/interesting scientific problem that your paper either solves or addresses. You should draw the reader in and make them want to read the rest of the paper.

The next paragraphs in the introduction should cite previous research in this area. It should cite those who had the idea or ideas first, and should also cite those who have done the most recent and relevant work. You should then go on to explain why more work was necessary (your work, of course.)

Other things that might belong in the introduction include:

1. A statement of the goal of the paper: why the study was undertaken, or why the paper was written. Do not repeat the abstract.
2. Sufficient background information to allow the reader to understand the context and significance of the question you are trying to address. All cited work should be directly relevant to the goals of the thesis. This is not a place to summarize everything you have ever read on a subject.

3. Proper acknowledgement of the previous work on which you are building. Sufficient references such that a reader could, by going to the library, achieve a sophisticated understanding of the context and significance of the question.
4. The questions that you are addressing and/or the hypotheses that you are testing.
5. An explanation of the scope of your work, and especially what you will and will not be included.
6. A verbal "road map" guiding the reader to what lies ahead and which clearly states where introductory material ("old stuff") ends and your contribution ("new stuff") begins.

You should break up the introduction section into logical segments by using subheads.

Methods. The methods section contains information that allows the reader to assess the believability of your results; that is, the information needed by another researcher to replicate your results. For papers that include lab experiments, describe the materials, set-up, equipment, calibrations, etc. For papers that include field observations, describe the field site and why it was selected, when the data was collected, data collection protocols, field equipment and procedures, etc. For papers that use other people's data, describe the databases that were accessed and the way in which data was vetted and analyzed. For papers that use models, describe the source of the model and something about the theory by which it functions. In all cases, special attention should be paid to limitations, assumptions, and range of validity.

Citations in this section should be limited to data sources and references of where to find more complete descriptions of procedures. The Methods section should not include descriptions of results.

Results. The results are actual statements of observations, including statistics, tables and graphs. The results should not be interpreted in this section – save that for the Discussion section. Lay out the case as for a jury. Present sufficient details so that others can draw their own inferences and construct their own explanations. Use S.I. units (m, s, kg, W, etc.) throughout the thesis. Mention negative results as well as positive.

Break up your results into logical segments by using subheadings

Key results should be stated in clear sentences at the beginning of paragraphs. It is far better to say, "X had significant positive relationship with Y (linear regression $p<0.01$, $r^2=0.79$)" then to start with a less informative statement like "There is a significant relationship between X and Y". Describe the nature of the findings; do not just tell the reader whether or not they are significant.

Quarantine your observations from your interpretations. The writer must make it crystal clear to the reader which statements are observation and which are interpretation. In most circumstances, this is best accomplished by physically separating statements about new observations from statements about the meaning or significance of those observations. Vast bodies of geological literature became obsolete with the advent of plate tectonics; the papers that survived are those in

which observations were presented in stand-alone fashion, unmuddied by whatever ideas the author might have had about the processes that caused the observed phenomena.

Discussion. The Discussion section should start with a few sentences that summarize the most important results. The discussion section should be a brief essay in itself, answering the following questions and caveats:

> What are the major patterns in the observations? (Refer to spatial and temporal variations.)
> What are the relationships, trends and generalizations among the results?
> What are the exceptions to these patterns or generalizations?
> What are the likely causes (mechanisms) underlying these patterns resulting predictions?
> Is there agreement or disagreement with previous work?

Interpret results in terms of background laid out in the introduction – what is the relationship of the present results to the original question? What is the implication of the present results for other unanswered questions in earth sciences, ecology, environmental policy, etc.?

There are usually several possible explanations for results. Be careful to consider all of them rather than simply pushing your favorite one. If you can eliminate all but one, that's great, but often that is not possible with the data in hand. In that case you should give even treatment to the remaining possibilities, and try to indicate ways in which future work may lead to their discrimination.

Avoid bandwagons: A special case of the above. Avoid promoting a currently fashionable point of view unless your results really do strongly support them.

Make sure to communicate the things we now know or understand that we didn't know or understand before the present work. Include the evidence or line of reasoning supporting each interpretation. Explicitly state why each new result is significant; that is, why the reader should care.

This section should be rich in references to similar work and background needed to interpret results. Be careful, however, not to make your discussion section too long or verbose!

Conclusions. The Conclusions should restate the strongest and most important conclusion that you can make from your results. It should be stated clearly and simply, to help the reader remember it. You should refer back to problem, as posed in the Introduction, and describe the conclusions that you reached from carrying out this investigation, summarize new observations, new interpretations, and new insights that have resulted from the present work. However, do not repeat word-for-word the abstract, introduction or discussion.

Include the broader implications of your results.

Recommendations. The Recommendation section provides an opportunity for you to explain how your research can be used in the future. If your research involves a societal problem, you can recommend remedial action to solve the problem. If your research has identified unexplained phenomena, you can recommend further research to fill in gaps in our understanding. And you can suggest directions for future investigations on this or related topics.

Acknowledgments. In this section you can thank anyone who helped you with your research, who provided you with data, samples or material, or who supported you financially.

You should include the sentence: "The author gratefully acknowledges support from the Lamont Summer Intern Program, which is funded by the National Science Foundations through its Research Experiences for Undergraduates Program OR the Earth Institute of Columbia University and its affiliates, OR the International Ocean Discovery Program, Barnard College, OR the Southern University of Science and Technology (China) OR private donors.

You should also check with your Intern Advisor to see whether additional funding sources should be acknowledged.

Bibliography. The bibliography is an alphabetical list (by author) of all the papers that you cited in your paper. (It does not include papers that you did not cite, even though you may have read them). By convention the following is considered mandatory:

The last name and first initial of the complete set of authors,
The full title of the paper
The name of the journal and volume number
The page range
The year of publication
The DOI

Many different formats are in use for ordering the information in a given bibliographic reference. You should be guided by the format you most often encounter in the journals that you relied upon for your research. This one is pretty common:

Author list (year). Title, Journal, volume, pages, DOI

E.g.

Menke, W., P. Skryzalin, V. Levin, T. Harper, F. Darbyshire, and T. Dong (2016), The Northern Appalachian Anomaly: A modern asthenospheric upwelling, Geophys. Res. Lett., 43, 10,173–10,179, doi:10.1002/2016GL070918

In any case, pick a single format and stick with it!

Many different ways are used to cite the papers within the text. Again, you should be guided by the format you most encounter in the papers you use. But citing the paper, above, as (Menke et al. 2016) is pretty common way to do it. If there are only two authors, the last names of the two authors should be cited like this (Menke and Menke, 2016).

Figures. Every figure should be accompanied by a caption. The caption should start with the figure number (e.g. "Figure 1), and then have a paragraph that explains the figure. Be sure to explain the overall figure (e.g. "Map of the study region") and each item contained in the figure (e.g. "Seismic stations (triangles) and earthquake hypocenters (stars) are shown). Ending the caption with a sentence pointing out a major feature is sometimes helpful (e.g. "Note that most earthquakes occur in a northeast-southwest striking zone").

You must "call out" each figure in the text. For example, "A map of earthquakes (Figure 1) indicates that most occur in a northeast-southwest striking zone thought to be a strike-slip fault".

Figures should be numbered so that the call-outs are sequential. Do not refer to figure 4 before you refer to figure 1!

You may either scatter the figures throughout the text, or append them to the end of the paper. A figure's caption should be placed immediately after the figure (and preferably on the same page).

Tables. Tables are hard to read, so use them sparingly. Every column in the table should have a header that gives the variable name and units of measurement. Every table should be accompanied by a caption. The caption should start with the table number (e.g. "Table 1"), and then have a paragraph that explains the table. Be sure to explain the overall table (e.g. "table of station locations") and any information about a column that won't fit into the column header (e.g. "The latitude and longitudes were determined with GPS, and the elevations with a barometric altimeter").

You must "call out" each table in the text. For example, "The measurements were made by nine seismic stations (Table 1) arranges in 3 by 3 grid".

Tables should be numbered so that the call-outs are sequential. Do not refer to table 4 before you refer to table 1!

You may either scatter the tables throughout the text, or append them to the end of the paper (and after appended figures). A table's caption should be placed immediately before the table (and preferably on the same page).

Appendix. The Appendix provides a place for ancillary material that you want to preserve but which is not directly used in the paper. For example, suppose that you analyzed ten photographs in your paper, and that your main results are in a graph that shows a trend between features. While you might only show one photograph and the figure documenting the trend line in the body of the paper, you can put all ten in an Appendix.

Obviously, while an Appendix will work for 10 photographs, it won't work for 10,000 of them. Appendices are not always that useful!

An Appendix can contain text, figures and tables, just like the main paper. Figures and Tables should be numbered separately from the main paper, starting with Figure A.1 and Table A.1 (where the "A" is for "Appendix"). Traditionally, the appendix does not contain any references. Note: We gratefully acknowledge that we drew heavily upon the Barnard College Environmental Sciences Department's "How to Write a Thesis" website (https://cool.barnard.edu/envsci/) in preparing this document. It is attributed to Kim Kastens, Stephanie Pfirman, Martin Stute, Bill Hahn, Dallas Abbott, and Chris Scholz.