How to write a scientific paper

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"In science one tries to tell people, in such a way as to be understood by everyone, something that no one ever knew before. But in poetry, it's the exact opposite". Paul A. M. Dirac (1902-1984)

Preface

The purpose for writing a scientific paper is to convey new scientific results to the scientific community. The paper should be as short as possible, but on the other hand, it must contain all the essential information which has led to the new results described in the paper. It must contain all information which other scientists need in order to verify your results. Note that a scientific paper is not a record of your scientific activity for a given time period (which your employer might ask you to write). The reader of your paper is not at all interested in the state of knowledge you presently have, but only in your new scientific results. These new results must be presented in the paper in a very concise manner.

I recommend that, before you submit the paper to a scientific journal, you ask one or two of your colleagues to look through your manuscript with a very critical eye. Ask these colleagues to convey all the criticism (with respect to content of the paper, the logical structure, the scientific phrasing, the English wording, etc.) to you and tell them beforehand that you will not feel insulted by their positive criticism. Criticism is an essential and indispensable part of science. My experience is that Asian scientists often have problems in criticizing fellow scientists and accepting critical remarks from them. But you have to get used to it and practice it in order to become a good scientist and be able to write good scientific papers. Receiving positive critical comments on your manuscript from your colleagues greatly helps in improving the quality of your paper, avoiding nasty comments from the reviewers or even the rejection of your paper for publication. A manuscript which you submit for publication is structured as follows:

1. Title Page

The title page must contain the title of the paper, the names of all authors and the names of their institutions. If an author has performed most of the research of the work at his previous institution, then he should put the name of his previous institution on the paper and add an asterisk to his name saying at the bottom of the page: ”Present

address: ……. “. In some journals also the e-mail addresses are required.

2. Abstract
3. Text
4. References
5. Figure captions
6. Tables
7. Figures

1. Title

It is often advisable to choose a preliminary title (“working title”) with which you define for yourself what you want to present in the paper. The final title should, on one hand, be as short as possible, but on the other hand, it should contain as much information as necessary to characterize the topic of your paper. Note that most of the readers of scientific journals only read the titles of the papers. The title must inform the reader in a brief and precise manner about the content of the paper. Abbreviations should be avoided. The title should show whether it is a theoretical or an experimental paper. You should allow yourself a lot of time for choosing the right title. I recommend to write down first all key words which you consider indispensable to characterize the content of the paper. Then you should combine these key words to a title. I usually compose from these key words three different alternatives for a title. Then I show them to colleagues and ask them which of these three alternatives they like best. But always bear in mind that the title should not to be too long.

2. Abstract

The abstract is after the title the second most important part of the paper. You should devote much time to write the abstract because the entire scientific paper will be read only by very few scientists, but the abstract by many. The abstract must tell the reader what the subject of the paper is, on what it is based, and, above all, what new results are presented. The most important results have to be stated in a short and precise manner in the abstract. It is not enough saying that the paper deals with this and that but not mentioning the results. This is a common mistake made by many authors. It is absolutely necessary that the hard facts which came out of your investigations are mentioned in the abstract.

If it is a theoretical paper, then you have to state what equations and approximations you have used. If it is an experimental one, then you have to state what experiments you have carried out, and eventually also what kind of data analysis (if not standard) you have used.

When writing the abstract, keep in mind that it is read also by scientists who have

another background and an education different from yours. Be aware that also scientists from neighboring disciplines may be interested in your paper who are not familiar with your scientific “jargon” and who do not know all the abbreviations commonly used by scientists working in your field. This implies that all abbreviations which you might use in the abstract must be explained when you first use them. As an example I mention “SAR”, which is often found in abstracts of papers dealing with remote sensing of the earth surface using radars. In this case SAR stands for “Synthetic Aperture Radar”. But in microwave technology SAR also denotes “Specific Absorption Rate”. However, most people associate SAR with “Search and Rescue” and Chinese people with “Special Administrative Region”. Therefore, if you want to use SAR in your abstract, write first the full name and put “SAR” behind the full name in parentheses. After that you can use the abbreviation “SAR”.

The abstract should not contain references. The abstract must be an autonomous part of the paper. This implies, e.g., that all abbreviations explained in the abstract have to be explained again in the main part of the paper.

The abstract must not be too long (e.g., Journal of Geophysical Research. recommends a maximal length of 250 words), however, it must contain all the important information of your investigation. Make sure that you use precise formulations. I have made the experience that it is a very difficult task to write a good abstract. It took me often 1-2 days to compose a good abstract.

3. Introduction

If you have attracted the attention of the reader to your paper through your good title and well-written abstract, then, most likely, the reader will turn next to the final section of your paper, which is often termed “Conclusions”, ”Discussions and Conclusions” or “Conclusions and Outlook”, and will look at the figures. Thus after the title and abstract, the next most important parts of the paper are the introduction, the final section, and the figures.

In the introduction you should give answers to the following questions:

(a.) Why have you written the paper? Why should the scientific community be interested in your results?

(b.) For what and for whom are your research results relevant? Can your results be applied for solving urgent societal problems? Or are they of importance for fundamental research? Or do they solve a technical problem?

(c.) On which previous papers (written by you or others) is your present paper based? What results have other scientists already obtained previously?

(d.) Why are the results presented in this paper “better” than the ones obtained by other authors? What is special in you paper? How does your present paper compare to other papers? Have you used a different data set, a different analysis technique, a

different model, or a different approximation?

In the “Introduction” you should briefly describe important results which other authors or yourself have obtained previously and give the references. Refrain from quoting your own papers too excessively (a mistake that is often done, in particular by American scientists). You should quote all the important papers dealing with this subject, and list them in chronological order (older papers first, newer ones later). Do not forget to quote also the first papers published on this subject even if you have not read them yourself. You should quote at least one or two papers of each research group who have contributed important results to this field of study. Be very careful in choosing the references and make sure that you have not forgotten important papers. Remember that, before your paper is published, it has to go through a review process. The editor of the journal usually sends your manuscripts to three scientists which are members of different research groups working in this field. My experience is that the reviewers often criticize that the authors of a submitted paper are not aware of some important papers written by members of other research groups.

It can get quite embarrassing if you have not mentioned any paper of the research group to which the reviewer belongs. Thus it is absolutely mandatory to get well acquainted with the literature. You may carry out the literature search by using the internet or by screening the latest issues of scientific journals and the proceedings of recent conferences. Another possibility, which I often use, is to consult scientists who have worked for a long time in this field and ask them about the most relevant publications. Often important research results are published first in conference proceedings, and when they are finally printed in journals (often 2 years later), they are outdated. The reason is that the review process and the publishing often take a very long time. If you cannot find the paper in your library (as a hard copy or in electronic form), ask the author for a reprint. Another way of getting access to a paper is sometimes by looking at the homepage of the author or of his institution. There you often find a pdf file of the paper.

In the last part of the Introduction, you should briefly mention the principal results contained in the paper (2-3 sentences), but should not give details. At the very end, you should describe the structure of the paper. (“The paper is structured as follows: …”.) Not more than one sentence should be used to describe the content of a section. (E.g., “In section 3 we describe the experimental set-up.”)

4. Main Part

The main part of the paper usually consists of several sections for which you have to find adequate headings. Often it is useful to divide a section into sub-sections.

If your paper is an experimental one, you should first describe in which framework

(project) the investigation was carried out. Then, in different sections, you should describe the instrument (only if they are not standard), the data analysis, and the results. In another section you should compare your experimental results with model results or, if appropriate, with experimental results obtained by other authors.

If your paper is a theoretical one, you should present the theory in the second section (following the Introduction), the numerical or analytical methods in the third section, and the results in the fourth section. Results are best presented in the form of figures. You should pay much attention to the formulation of the figure captions. The reader should understand the figures without being forced to consult the main text. The figure captions have to be reasonably short; details can be described in the main text.

You must explain the meaning of all symbols used in the paper. Make sure that you have not used the same symbol for different variables or constants. Use always the metric system (not feet, inches, miles, pounds, etc.) and SI units. Never start a sentence with a symbol because this may lead to misunderstandings. E.g., do not start a sentence with: “g denotes the gravitational constant”, write instead: “Here g denotes the gravitational constant.”

5. Final Section

In the last or final section, which is often called “Conclusions”, “Summary and Conclusions”, “Summary”, or “Summary and Discussion”, you should discuss your results critically. Here, you should summarize your principal results in more detail than in the abstract. In particular, you should point out how and why your results differ from the results obtained by others or you should state that they confirm previous results.

In this final section, you should give answers to the following questions when they are applicable:

(a) How significant are my results?
(b) How large are the uncertainties or error bars?
(c) Under which environmental conditions have I carried out my experiment?
(d) Which assumption have I made for obtaining my theoretical results?
(e) What approximations have I used?
(f) Can my results be generalized? (Here it is allowed also to speculate a bit.)
(g) Which further studies on the subject of my paper do I recommend?
(h) What kind of difficulties do I expect in these future studies?

In some cases it may be appropriate to divide the final section in two sections, which you may call “Conclusion” or “Conclusions and Outlook”. In summary: In the final section you should summarize the main results of the paper in some detail and discuss them critically. The merits and also the shortcomings of your investigation should be mentioned. As a good scientist you must be honest and must not hide anything under the carpet.

As already mentioned previously, the final section together with the abstract, the introduction and the figures are the most important parts of the paper. These parts of the paper are read by many scientists, but the main part is read only by very few. Therefore you should devote much effort in writing the final section.

6. Figures

Figures convey information to the reader more effectively than a text does and they are also preferred by the reader. Make your paper more concise and more easily understandable by using well devised figures and diagrams. Figures must not be overloaded with curves and symbols. By looking at the figures, the reader, in particular the specialist, should be able to grasp the results of your paper immediately without being forced to read the whole paper. Therefore the symbols inserted in the figures and the figure captions should be well readable and easily understandable. The figures should not constitute a crossword puzzle to the reader. The symbols and numbers inserted in the figures should be chosen as large as possible such that they can still be read after their size has been reduced in the publishing process.

Make sure that the symbols and letters used in the figures correspond to those in the text. The figure captions should be short, but should contain all information needed to understand the figure. If a figure caption gets too long, you may shorten it by referring to a formula given in the text. (E.g., “Here Fr denotes the Froude number defined in equation in (9)”) My experience is that it is not an easy task to write good figure captions. I recommend to get inspirations from figure captions written by other authors.

7. Tables

Tables are often very useful because much information can be put in them which the reader easily can grasp. E.g., it is advisable to put the parameters of an instrument or the meteorological parameters encountered during an experiments in a table. Do not forget to state in which units (e.g., meters, local time or UTC) the numbers are given.

8. References

The “References” are also a very important part of the paper and should be chosen with great care. My experience is that beginners are often very negligent in putting together the reference list. You must check line by line, whether the page numbers and the years of publication are correct. It is mandatory to put the references in a format which the journal prescribes. The formats often differ from journal to journal. Make sure that all references in your reference list have the same format. Especially when you use “copy” and “paste” you are bound to end up with a non-uniform reference list which is unacceptable. Usually you must order the reference list by the initial letters of

the authors. If more than one paper of an author is listed, then the paper published first has to appear first in the list. If an author has published more than one paper in a year, then his papers must be differentiated by putting the letters a, b, c, … behind the year of publication. (e.g., 2005a, 2005b.) If papers are listed which were written together with co-authors, then they must be listed after the papers where the first author is the only author.

In the references list the names of all authors must be given. References like "Fischer, J., et al., 2005" are not acceptable and are very unfair to the co-authors. You should aim at referencing only those publications to which the reader has easy access, preferably international journals. Internal reports that cannot be accessed by internet should be banned from the reference list. But if a certain internal report was crucial in obtaining the results described in your paper, then you have to give very detailed information on this paper such that the reader can get it from the institution in which the internal report was published. Readers of your paper may also ask you for copies of this internal report. You are supposed to grant this request.

If you reference a paper that was published in a conference proceeding, then you have to mention the title of the conference, the location, the date, the name of the organization which has published the proceedings, and the publication number.

9. Acknowledgements

The "Acknowledgements" are also an important part of the paper to which many authors pay little attention. You should acknowledge all people who have significantly contributed to your paper and all organizations which have financed your research and which have provided the data. E.g., the European Space Agency (ESA) and the German Weather Service insist that they are mentioned in the Acknowledgements if they have given you the data free of charge.

I recommend not being too stingy in mentioning people in the Acknowledgements who have helped you in carrying out your research. Mentioning them often opens you doors for future help!

Do not forget to send a reprint or copy of your paper to all those people who you have mentioned in the "Acknowledgements" (preferably with a hand-written personal inscription on the first page).

Appendix: General Remarks

A 1. Writing a Comprehensible Paper

A scientific paper must be written in such a way that it is easy to read and understand. The famous American physicist and Nobel Prize winner Richard P. Feynman once said: “If you can’t explain your theory to a freshman, then something is wrong with your explanation or with your theory”. Be aware of the fact that your paper must also be understood by scientists who do not have your scientific background and who have not spent years like you have, to get acquainted with your research topic. Most of the potential readers of your paper do not know all the abbreviations and acronyms (new words formed from abbreviations) which you use everyday in your laboratory when communicating with your fellow scientists. Therefore you should aim at using words which are understandable for all persons having a reasonably good background in natural science. Before you introduce any abbreviation, you have to write the full word or explain it. You should aim at using only abbreviations which are familiar to a large group of scientists, and not only to few scientists, like the members of your research group.

In order to test whether the text is understandable, I often try, like an actor, to slip into the body of another imaginary person and read my text again from his view-point. If I can still understand my text well, I am satisfied and keep the text as it is, otherwise I change it. You can do even better by asking a friend with a science background (but not a colleague from your laboratory) to read your text and then ask him/her what information he/she has extracted from it. You will be astonished to find that this person, who is not a specialist in your field, often extracts completely different information from your text than you do.

The reader must be able to grasp the information contained in each of your sentences immediately. You should always remind yourself that the paper must be written in such a way that it is easy to read and easy to understand. Do not compose the paper like a crossword puzzle such that the reader has always to make guesses. Often it helps in composing a good text when you constantly ask yourself: “What information will I finally convey to the reader of my paper?” or “Why are my results better than the ones of other authors?”

A2. Structure of a Scientific Paper

The structure of the paper does not have to follow rigid rules, but must comply with logic. The sections must be put in a logical order. In a mainly experimental paper the description of the instrument has to precede the discussion on theoretical issues.

The heading or title of a section must be carefully chosen such that it conveys precisely its content. E.g., in a section with the heading “The experiment” you can not

describe theoretical issues. As done in mathematics, you first have to mention the assumptions or prerequisites, then you make the proposition or statement, and then you prove it. In general, statements are only true under certain conditions or assumptions, which must be stated clearly in the paper.

A3 Formulation of the Sentences

Never write that something is “large”, “small”, “long” or “short”. These words must be referenced to something. Note that something that is small for an elephant may be large for a mouse. Something that for a radio technician is a high-frequency signal, is for a radar technician a low-frequency signal.

You should always use in your paper precise scientific formulations and not ambiguous words. Never use “words of the street” (e.g., “junk”, “dirty”, “shabby”) and “jargon words” (e.g., “boss”, “MAC” for Macintosh computer, “tunnel” for a wind wave tunnel). Words like “nice”, “marvelous”, “bad”, etc. have no place in a scientific paper. Also words like “excellent”, “extraordinary” should be avoided.

Never use different words for the same scientific term. If you do it, then the reader gets confused and is not sure whether you really mean with the two words the same thing. In a scientific paper you should never sacrifice precision for linguistic diversity. Leave linguistic diversity to novel writers and writers of love letters. Unlike in novels, you are allowed to use the same word again and again in scientific papers. Avoid words which have multiple or ambiguous meanings. Clear and precise formulations have to go along with a clear content.

Avoid in you paper “filling words”, like “interesting”, “natural”, and superlatives like “very”, “full”, “highly”, “excellent”, “extraordinary”, etc. If you write in your paper “The theoretical results are in excellent agreement with the observational data”, then the critical reader gets immediately suspicious.

Use always the special term, not the general one, e.g., use “galvanometer” or “microwave radiometer” instead of “instrument”. Try to avoid “elongated verbs”: Do not say “make the decision”, say instead “decide”; do not say “make the experience”, say instead “experience”.

A sentence must be structured in such a way that the reader can understand it immediately and not only after reading it several times. This implies that the sentence must not be too long and must not contain too many subordinate clauses or nested sub-sentences. The sentences should be short or medium in length (typically 15-20 words long) with only one or two subordinate clauses.

Never put essential information in parentheses. Only auxiliary information which is not essential for understanding the paper, but which may help to understand the text better, should be put in parentheses.

Write clearly structured sentences, do not describe similar items with different words

and use in a sentence the same units. E.g., if you want to describe the height of two persons, do not write: *"The 21 years old female student is 160 cm tall and the boy, whose age is 23 years and who is also a student, is … 70 inches tall."* But write instead: *"The 21 years old female student is 1.6 m tall and the 23 years old male student is …1.78 m tall."*

Nouns that are used on an equal basis side by side in a sentence should also be followed by corresponding equal attributes. Do not write: *"Building A is 120 m high and building B has 3000 m^2 office space*." Instead you should write in one sentence how high the buildings A and B are and/or how much office space both buildings have. Do not write "*We are three authors, two are professors at the University of Hamburg and the other works at the University of Plymouth"*. Instead you should write "*We are three authors, two are professors at the University of Hamburg and the third one is a senior scientist at the University of Plymouth"*.

Describe only those objects in the paper that are relevant for the subject of your paper. E.g., if your paper deals with the harbor of Singapore, do not describe the harbor of Hong Kong. This only makes sense if you want to compare both harbors.

Examples for wrong and correct formulations:

(1) Wrong: *"The measured value is greater than the theory"*.
Correct:*" The measured value is larger than the theoretical value"*.

(2) Wrong: *"The apple and the pear have prices of 20 cents and 30 cents which weigh 40g and 35 g."*
Correct: *"The apple which weighs 40 g costs 20 cents and the pear which weighs 35 g costs 30 cents."*

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A4. The Ethics of Scientists

Scientists have to obey an ethical rule which says that they are committed solely to the scientific truth. This ethical rule is similarly binding for scientists as the hippocratic oath for medical doctors. You are not allowed to soften this rule, neither for the benefit of obtaining research funds more easily nor for the benefit of enjoying your showmanship in the media.

It is not acceptable to make in your paper statements that are based on "shaky" assumptions or on un-sound reasoning. If you mention something that you have not proven, but which you suspect to be correct, then you must clearly state it. E.g., you may write: *"We suspect that these results can also be applied to cases where..."*
Furthermore, you must state your results clearly and not describe them in fuzzy words which could give rise to misinterpretations by the readers.

You should be very careful in not putting wrong statements in your paper. Usually a statement is only true when certain conditions are fulfilled. When you do not mention

these conditions, then your statement is wrong from a scientific point of view and thus unacceptable.

A5. Publishing Issues

You should always aim at publishing your research results in well-known international peer-reviewed journals. That ensures that they become known to a large number of scientists. Publishing your results in such international journals makes you known in the international scientific community and it also helps you in climbing up the career ladder. In some countries the scientific merit of a scientist is quantified by multiplying each of his / her publications with the impact factor of the journal and then forming the sum.

Research results that are not published are practically worthless (however, exceptions may apply for military and some industrial research). Results published in internal reports or in national journals most often are ignored by the international scientific community. My experience is that scientific results published in papers which are not written in English do not make their way into the international scientific community and therefore often do not contribute to the advancement of science.

Always keep in mind that, if you work at a public institution, your scientific work is funded by tax payers and they expect something in return from you. Your products are the scientific papers. The results of your scientific work have to be sold similarly as the products of a farmer. Not publishing your results means that the products of your work do not come to the market. They will age away, get spoiled and finally become worthless. In this case the institution which has funded you for carrying out the research has wasted tax payers' money.

It is also important to publish the paper in the "right" journal. World-wide there exist more than 35000 journals publishing papers in the field of natural science. When choosing the journal you should answer the following questions:

(1) Are there good chances that the journal is read by those scientists who you would like to read your paper?
(2) Has it a wide international distribution?
(3) Can you find it in many libraries?
(4) Is its impact factor high? (You can get information on the impact factor of a scientific journal from the internet.)

The higher the impact factor of the journal in which you publish your paper, the higher you will you be ranked in the scientific community. However, the higher the impact factor of a journal, the higher is also the rejection rate. E.g., the rejection rate for "Nature" and "Science" is higher than 90%.

I recommend that, before you submit your paper to a journal, you ask an experienced senior scientist for advice.