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PRINCIPLES OF SCIENCE WRITING

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INTRODUCTION

These notes are part of the web site of [SCITEXT CAMBRIDGE](#), the worldwide editing service for scientific documents based in the university city of Cambridge, England. You are welcome to print or download this page. If you find it useful and if you maintain a web site carrying diverse hyperlinks, please provide a descriptive hyperlink to our homepage.

The notes below are provided as a service to the scientific community. They set out the principles for writing a scientific document that is well-structured at every logical level. Some tips on the use of English in science writing are included in the [list](#) set out before the bibliography; this list has been compiled by studying actual scientific writing. Systematic improvement of written English involves learning the structures of the language - its syntax and grammar - and reflects primarily in better sentence construction. It is treated in some of the books recommended in the [bibliography](#) at the end of this document.

On-line courses or books containing exercises are not an adequate substitute for learning by personal attendance at a course. The greater involvement and personal guidance imprint the material in your mind in a way that enables you to deploy it effectively. SCITEXT's [courses](#) on science writing fully cover both structure and style, and distinct courses are available for native and for non-native English speakers.

Most books on science writing fall into one of two categories: (1) essays which recognise and categorise poor writing but which do not actually help you improve your own writing; (2) long lists of rules for good writing, which are too numerous and diverse to be learned explicitly. People do not learn writing and other skills by committing long lists of rules to memory and checking every sentence. Below, we set out principles which are general enough to be few in number yet tangible enough to be learned.

You can also read our [history](#) of science writing.

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HOW AND WHEN TO WRITE

The way you write must follow from the way you work, not *vice versa*. The composition of a piece of science proceeds by an iterative process between thinking and writing. Should you be blocked, the most common cause is mistaken belief that the next step is easy when in fact it is difficult; try to identify precisely what that step is, in order to break it down. It has always been recognised that writing aids this process, and writing of this sort need be comprehensible only to yourself.

In both the writing you do while gaining your understanding, and in writing the formal draft of the work, it is up to you whether to write by hand or to use a word processor, perhaps with notes adjacent. The important thing is to distinguish learning-for-yourself writing from teaching-of-others writing. If you find you are blocked on either of longhand or machine writing, try the other. Many people find longhand writing is better for a tricky paragraph or a continuous section, or when the time taken to type mathematical or chemical formulae would disrupt the flow of thought.

Once the iteration between thinking and writing has converged to something coherent, you are ready to write the version which is intended for public view. You will now be holding the whole scientific structure of the material, and the inter-relations of its parts, in your head. Only after you have the full structure of the material in your head will you know the best way (for example, the best order) to transmit the components of that structure to the reader. You build the structure of the material from the outside in - from its connections with the rest of science - and then go back out again.

Readers come to understand the material by reconstructing the structure of the material for themselves, guided by the writer. You must therefore understand your readers as well as the material, and simulate your targeted reader (layman, peer, etc) in your own mind. Moreover, it is only after you hold the full structure in your head that you can mould it successfully to the standardised structure of scientific documents. Even then, expertise is involved in the narration. Follow the narrative path which best allows readers to reconstruct the structure for themselves by forging the appropriate associative links. The idea of narration extends also to style: sometimes it is better to pose as an authority explaining a doctrine; sometimes to join the reader in a search after truth, in which questions are explicitly posed and answered. Your ideal is to stimulate readers to raise for

themselves the point you tackle next.

In all cases, give readers the building blocks, tell them where these go, and above all *why*. The reconstruction needs to be explicitly guided by knowledge of what end you are working towards. This rule applies at every level: overall; in each section; in each subsection. Then readers are pulled along the path by the author, who is at every moment just ahead in the right direction. Without this teleological approach readers will wonder why each step, in itself quite unremarkable, is being taken. The author's achievement lies in discovering the correct route through the maze, and not in a series of unremarkable steps; correspondingly, readers need to be told in advance what the author is trying to do, to see how each step advances toward that goal. Failure to do this means that readers will not see the point until very close to the end. They will then have to go back and fill in the hierarchy of guiding purposes for themselves, and the writing will not be comprehensible in a single pass. It is provision of this hierarchy of purposes which distinguishes writing for others from your working notes.

- when to write: once you hold the full structure in your head
- how to write: to best allow readers to reconstruct this structure. Be teleological.

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THE FIRST DRAFT

Do not delay once you are holding the overall logical structure in your head or you will forget what it was like not to understand the material, and find it harder to take the reader's point of view. A single paper should involve a single theme; if its logical structure does not proceed from a single stem, you should write more than one paper.

Write the first formal draft in whatever language you are most at home in, and translate if necessary *after*. Explaining is a difficult task: if you are diverted by problems of language, the standard of explanation will suffer. When translating, translate the *meaning*, not the words one-for-one.

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REVISING AND WHEN TO FINISH

Check the first draft for accuracy in calculations, equations and references. You will almost certainly want to make revisions both in structure and in style. You may have over-explained some things which you initially found hard to understand, or you may find that a point is not so closely related to the main line of development as you had thought. Prune it. You may have under-explained other points which you found easy to understand; always consider the reader who is fresh to the material. It is also common at this stage to change the paragraph breaks. Revise after a little time has elapsed, so that you have distanced yourself slightly from the material and the finer details of the working are no longer uppermost in your mind. By doing this you more nearly simulate your readership, while bringing to the task your own unrivalled knowledge of the material. You are likely to be on the right track if the result is shorter.

Once you are satisfied with the hard copy, show it to someone else. Better than simulating the reader is finding a real one! While you see

in your writing what you mean, others see in it what you say; their comments will reveal how closely the two coincide. The more people you involve the better. Modify the document in the light of their comments and suggestions. Co-authors must all inspect and agree on a manuscript; their interaction is useful to the exposition.

Having done this, run a spellchecking routine to correct any remaining or newly introduced typographical errors, and check that all equation, table and figure numbers are in sequence. You are then ready to submit the work.

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DIFFERENT TYPES OF SCIENCE WRITING

Science writing divides, not always clearly, into *tutorial* and *research*. Publication as a book or as a paper is largely a matter of length - although it is accepted that you can do things much more your own way in books.

TUTORIAL WRITING

- advanced textbook (graduate level)
- extended review paper
- overview paper (typically, invited at a conference)
- basic textbook (undergraduate level)
- summary to workers in other areas of the same science
- summary to non-scientists

RESEARCH WRITING

- monograph
- research paper
- letter (typically, in a rapid communications journal)

Unlike research works, non-commissioned tutorial works are written at a level of the author's choosing, for the chosen audience. Their purpose lies in instructing these audiences in facts and ideas that are already largely known.

You may wish to persuade the audience to adopt one point of view against others (unanimity in science is rare); to do this, it is best to present your own point of view explicitly and in depth, *outlining* the distinctions which make it superior, and why. Supposedly impartial comparisons rarely succeed; nobody writes well without conviction.

A graduate level textbook should be comprehensive and as technical as it needs to be (never more so, but not less so). It can assume knowledge up to first degree level, and a further discretionary amount which must be stated explicitly. If it is worked up from lecture notes, you need to include any material which you would normally leave to the students to fill in. An extended review paper should be the same as a graduate text, only shorter. It is probably the first thing which a new graduate student will be directed to read; write it as such. Mention present trends and unsolved problems. There should be a guide to the literature, but this need not be comprehensive: refer to the best papers explaining how to do something, to pioneering papers, and to generally *good* papers; alternative viewpoints should not receive equal representation. An overview paper of the sort presented as an invited paper at a conference will be technical and designed to keep the audience up to date in a field; it is often an unsatisfactory compromise between scope and length. Keeping an overview both comprehensive

and comprehensible is a skilled task; it does not follow that the best researchers (who generally get the job) are the best writers. Use a broad brush, but always give the *ideas*, in enough detail to allow genuinely interested readers to reconstruct the full argument. You must be ruthless in delegating to references anything even slightly away from the main stem of the story; "prune the tree". Basic textbooks speak for themselves; always state what knowledge you are assuming of readers, and what level you are taking them up to. Be consistent throughout. Summaries for workers in the same science, but in different areas of it, typically appear in the regular house magazines of the institutes of academic disciplines. Writers can assume a common vocabulary and philosophy but not more. Write as to an advanced undergraduate, and again make sure that enough information is given to allow the seriously interested reader to fill out the full argument. Nothing is more exasperating than an article which reads well superficially but on closer examination proves to be full of logical jumps and assumptions. This is always a result of the writer taking too much for granted of the reader. The same applies, with greater force, to writing for the layman.

The purpose of research writings is to propagate the new knowledge which you have discovered. A monograph differs from a paper only in length; it will cover the literature in greater depth, but only because more scene-setting is involved. From the *reader's* point of view the monograph is similar to a Ph.D. thesis, which has evolved, in line with how science is done, from defending a proposition which the candidate has read and pondered on, to the writing of original research. Many theses are published with little change as monographs. A letter, finally, is used to communicate a new result rapidly with the barest of detail or interpretation.

All of the formal types of writing have the same structure: title, abstract, introduction, meat of the piece, conclusions. In other words, you say in outline what you have done; introduce the ideas in relation to the existing literature and explain your motivation; do it; then summarise what you have done, what questions it answers and what new points it raises.

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THE PARTS OF A RESEARCH PAPER IN SEQUENCE

We now run through the standard structure of a formal scientific paper. The slightly differing structures of the other types will then be summarised as deviations from this. The usual structure of a paper is:

1. title
2. keywords and classification numbers
3. author(s) and affiliation(s)
4. abstract or summary
5. table of contents
6. introduction
7. main working
8. conclusions
9. acknowledgements
10. appendices
11. references

1. Title

The purpose of your title is to describe the contents of the paper in

very few words, and in a way which catches and holds the attention of as many people as possible. A good title which fulfils these requirements is therefore vital. If you fail to describe the contents accurately, most people will not read further to find out; casual browsers only give a paper one chance. You want to appeal to both expert and casual browsers.

Whatever provisional title you gave the paper during its composition, the title should be finalised once the paper is written, because you will then have gained your best perspective on the material.

Some practical tips in title composition are:

- catch the eye
- don't underspecify
- don't overspecify
- in a research paper, emphasise the main novelty
- don't use nouns as adjectives or verbs
- use keywords
- avoid specialist terminology
- avoid superfluous phrases and non-descriptive words
- consider changing the order of words or phrases
- consider using a colon followed by a subtitle

Keywords are increasingly used in automated literature searching, so you should ensure that the keywords which best specify your work appear in the title. Avoid terminology familiar only to specialists in the field of writing, especially acronyms and other abbreviations; your aim is to minimise the proportion of readers turning aside at each point, and non-specialists will not look further if they do not know what a word means. You should also avoid superfluous phrases such as *A study of...* and words which are only weakly descriptive, like *various* and *preliminary*. Clumsy phrasing can often be rescued by changing the order of words or phrases. Another rescuing device is the use of a colon to relegate some verbiage to a subtitle. You can consider writing the title as a question, or as an affirmation or negation. Question titles challenge the reader to continue further. Phrasing the title as an assertion is dramatic; it implies and answers a question. Some less imaginative journals do not allow questions or assertions in titles.

2. Keywords and classification numbers

Some journals allow (or require) a separate list of keywords. Where this is done, use all you wish up to the number allowed, and place them in descending order of priority. (If the journal publishes keywords in alphabetical order, consider dropping those of least priority.) Remember, though, that many journals and searching systems only use titles, so that use of the most important keywords in your title is still vital.

Some subjects now have a hierarchical coded classification scheme. Because of the connections between diverse areas, you might specify more than one number. List them in decreasing order of priority.

3. Author(s) and affiliation(s)

In multiple-author papers, decide the authors' order of priority and list them in descending order. If you all regard yourself as equal, say so; don't assume that alphabetical order (or any other) will be taken to imply equality.

- list authors in descending order of priority

- if all equal say so

4. Abstract or summary

Books on science writing often discuss the difference between an abstract and a summary, and between an "informative" abstract, used in research papers, and an "indicative" abstract, used in tutorial and review papers. In all cases the abstract or summary is a balanced, self-contained outline of the paper, intermediate between the title and the full content. These distinctions merely reflect differences of purpose between research writing and tutorial writing.

The abstract of a research paper is designed to inform readers who persist beyond the title what the paper is about, without their having to read the whole work. This purpose is mutually beneficial: there is insufficient information in a title for readers to decide reliably whether they wish to read the whole; writers will carry a larger audience beyond the title than without an abstract. Abstracts are also published in Abstracts reference volumes as a service to browsers. Abstracts should therefore avoid ultra-specialist terms, and they should be self-contained. The aim is to *abstract* the essence of the work. If the material explicitly and closely follows from a previous paper (by the same or different authors) the reference to this may be given, but the abstract should still be self-contained. The reader should not feel teased by hints of what is to come.

In an abstract everything is subordinate to communicating what the paper is about. Do not be afraid to spend a disproportionate amount of the abstract setting up underlying ideas: comprehension is your aim. Imagine you are explaining your work verbally to a colleague in three minutes. You should state what you did, how you did it, and give your conclusions, but be sparing as to why; the Introduction is the proper place to explain your motivations. Stress the single underlying theme of the paper. Since the author's perspective is clearest after the paper has been completed, that is when the abstract should be written. Do not bother with a preliminary version; you should have begun writing the paper with a preliminary draft of the Introduction.

Unless the paper is very short, abstracts of fewer than 150 words ignore detail which readers are capable of absorbing; more than 250 words causes saturation. (Verify this for yourself in a library.) Write the abstract holding these numbers in the back of your mind. Don't count words until you have finished or, if you are off target, you will distort the later parts. Once you have finished, you should reread the abstract and expand those points which are over-condensed and contract any which are over-extended. Only very rarely is the result too short; if it is only a little longer than 250-300 words, boil it down on a word processor (incomparable for this purpose); if it is more than about one-and-two-thirds as long, write it again from scratch.

TENSES. For use of past, present and future tenses of verbs in the abstract, please see the paragraph on tenses in the notes on the Introduction, just below.

- self-contained outline of the paper
- minimise specialist terms
- be prepared to spend a disproportionate amount of the abstract setting the scene
- imagine you are explaining your work verbally to a colleague over three minutes
- write it after the rest of the paper has been completed
- 150-250 words

5. The Table of Contents

This comes after the abstract because it is only after reading the abstract that browsers will know if they want to continue. A table of contents should include all section headings, sub-section headings (making clear on sight their subordinate status), and Appendices with their titles. Apart from hastening readers to any items they wish to peruse out of running order, the headings constitute useful information about the structure of the paper, and it is helpful in all but the shortest papers to list these in one place - even if the target journal does not do so. Many people, including the referee, will read the preprint. It follows that the headings of sections and sub-sections should be usefully informative.

- include all section and sub-section headings, appendices
- make their titles informative

6. The Introduction

The Introduction is the start of the paper proper; together with the end, it therefore plays the most important part in communicating your message. It *introduces* the reader to the concerns you have. Unlike the Abstract it is not self-contained: it leads the reader into the main working.

The Introduction is the place to set out the logical structure of the work and, additionally, to explain the overall purpose of the work and the motivation for it; the *why* of it. Without this it will make no sense to the reader no matter how well written. Raise the questions that made you curious, and why you were led to do the work. Explain what was the fate of those questions: to be answered, and what those answers are; to be circumvented or transcended; or to reveal fresh questions, whose fate must in turn be discussed.

The Introduction makes the logical structure explicit, by providing a map of the paper. By giving readers this map in advance, you allow them to hold the whole in their heads as they navigate through the separate components - which they must do in order to learn successfully. In parallel you must set out the corresponding hierarchy of purposes, by explaining how each section advances the argument toward the goal of the entire paper.

The first step in constructing a map is to define its borders and set the *context* of the paper, by making explicit what knowledge will be assumed of the reader, and what will be demonstrated. In doing this you will need to refer to other works; refer to as many as you need but not more - a research paper is not a literature survey. In setting context it is helpful to quote review papers, or books. A little history is often an effective way of telling your story. (There used to be too much of this; today there is too little.) If your work follows on from other published papers, quote them, but also outline what you need from them in order to make your paper readable by itself. The Introduction should make clear what was the position before your paper, and how your work changes it. Be clear about what existing material is re-interpreted or explained in your own words to assist your purpose, and what is genuinely original in your work.

Having set your context, fill in the map according to the logical structure of the material. Confirm that it satisfies the less tangible criteria of making clear the issues you address, the problems you tackle, the facts you communicate, the ideas you develop or challenge,

and their positions within the discipline. Interwoven with these should be your motivations, the overall result making plain the scope of the work.

In all but the shortest papers, the Introduction also states what is done in each separate headed section of the main working. Write in such a way as to make it clear why you segmented the material as you did.

Since the Introduction is the start of the paper proper, that is where you should begin your writing. Having written the paper, you then tailor the Introduction more closely to what emerged. Think of this tailoring as the last stage in writing the first draft, not the first stage in revising it.

TENSES. Facts *are* true: use the present tense to denote unchanging truths. When telling what the authors or other researchers *did*, use the past tense. For what is being done in the paper, use the past tense for referring back ("in Section 5 it was shown that..."). For referring ahead, use the future tense if the writer is thinking of the reader ("in Section 7 we shall see that..."), but the present tense if the writer is thinking of how the paper *is* set out ("in Section 7 it is shown that..."). For referral immediately ahead, the *shall* can be omitted: "we now show that...". These rules apply from the Introduction to the Conclusion; the Abstract is a self-contained condensation of the paper to which they apply separately.

- set out the logical structure of the work
- then run through the sections
- explain the aim of the work and the purposes of the sections in fulfilling it
- why you wrote it - perhaps a little history
- state what will be assumed and what demonstrated
- state what was the prior position and how the paper changes it
- begin writing the paper with the Introduction; revise it as soon as you reach the end

7. The Main Working

It is at this point that the individuality of the material asserts itself. Each section has a distinct structure, subordinate to the overall structure of the paper, and each sub-section has a structure which is part of the overall structure of that section, and is distinct from the structures of the other sub-sections. In some writing you will have complete freedom to choose this structure, in other writing a skeleton will be provided - such as the "Methods, Results, Discussion" of many papers in the biological sciences.

Parallel with this hierarchy of sub-structures is a hierarchy of aims. The overall purpose of the work is what we called, in the previous section, the *why* of it. Below this, each section should have a distinct aim, subordinate to the overall purpose of the paper, and each sub-section should have an aim which is subordinate to the aim of that section, and is distinct from the aims of the other sub-sections. The skeleton of sections and sub-sections proceeds from the hierarchy which the writer sees; it is when the aim changes that a new section or sub-section should be started. Always state at the start of a section or sub-section what its aim is so as to guide the reader throughout it to its end. Do not worry if you find you need to re-order the material; this is the first time that you are considering the reader's point of view instead of your own.

At this point advice is of a different type, concerned with expository

technique and style, not with the moulding of your material to the standard structure of scientific papers. The main principles of expository writing are the avoidance of ambiguity at every level, the maintaining of flow, the maintaining of the reader's confidence and receptivity, and the allocation of the correct amount of explanation at the correct rate to every point. The crucial unit of writing from the point of view of style is the sentence. If you change part of a sentence you will usually have to change the rest of it, and usually not have to change adjacent sentences.

The list of [tips](#) set out before the bibliography is an expansion of these principles. It is most helpfully used by comparing examples of your writing with it and then modifying these accordingly.

8. The Conclusion

The paper should end with a summing-up, which in all but the shortest papers should be a separate section. Your purpose is to convey the unity of the structure of the material, since this is what will implant itself in the reader's mind. The title of this section varies throughout the literature; commonly you will find Conclusion, Conclusions, Concluding Remarks, Summary, Summary-and-Discussion.

Whatever it is called, this last section is a summing up of the material, emphasising the unity of its structure and theme, and putting it in its wider context so as to give the reader an accurate perspective on it after the close-up view. Nothing should be stated which has not already been covered in the paper itself, but it can be stated in language which presumes that the reader is familiar with the contents of the paper. Emphasise the main points of the paper and how they alter the picture from before the paper was written. Do they alter the wider field in which the material is located; do they propose a new hypothesis or modify an accepted hypothesis; do they verify or disprove a hypothesis, or imply large changes in its plausibility? Explain to what extent the questions raised in the Introduction have been answered. You may also state what points need following up, what lines now look promising or unpromising, and you may speculate concisely as to what lies along them. Explain (if it is not obvious) why your paper stopped where it did.

- a summing-up
- stress the main theme - the unity of structure of the material
- no new material
- how the paper has altered things. New questions raised and *brief* speculations
- if not obvious, state why you stopped where you did

9. Acknowledgements

Thank your sources of funds if it is a condition of the funding, or if you feel it appropriate. Thank by name those people without whose personal intellectual influence the paper would have been significantly different. Explain briefly why you're thanking each person or group. Avoid the diffident phrase "I [we; the authors] would like to [wish to] thank...", for it fails to thank anyone; it merely states that you would like to. Do not "acknowledge" (with or without gratitude) or "express thanks"; simply *thank* - or at least state that you are grateful. Do not hide from the responsibility of being personal at the one point where it is mandatory. It is a matter of professionalism and courtesy to offer your thanks, and to do it gracefully.

- thank funders if required or desired

- thank those having a direct intellectual influence on the paper
- simply *thank*

10. Appendices

The purpose of an appendix is to accept subsidiary material, so that the reader maintains a continuous train of thought through the main development. Large amounts of data should obviously be placed in appendices. You may also need at some point in the paper to use a result which is not obvious or well-known, and which is not set out (at all, or satisfactorily) in the literature. In that case you should do what you would if it were in the literature: refer to it, but set it out yourself and place it separately, in an appendix. An appendix is for material of intermediate length: if the working is short, it should be integrated into the text; if long, it should be published separately. There is no "right number" of appendices for a paper of a given length; this depends entirely on the material.

Always give an appendix an informative title which explains its purpose to someone who has reached the point of referral to it in the main text; for example *Appendix C: Data on Dialysis Rates*.

- subsidiary material of intermediate length
- think of it as a separate piece of work, to which you refer

11. References

In the text, you should refer to papers which make specific points you need, and influential works which establish the context of your work. Whenever you refer to a work, make a note of it (on paper or computer file) and, at the end of the first draft, compile full details of every reference: authors in order and their initials, journal names in full, article titles in full, volumes, first and last page numbers (journals and themed collections of papers), year of publication, publisher and place of publication (and perhaps ISBN number) for books, editors of themed collections such as conference proceedings. Not all journals require all of these details, but you don't know in advance which will be needed; you may have to submit the paper to a second journal if the first rejects it, and you may need the reference again in further publications. Always conform to the style of the journal you choose.

- keep a running list during writing
- then store full details of each
- then write them in the house style of the target journal
- at the very back of the preprint, beyond the figures

Footnotes and Endnotes

Do not defer subsidiary points to footnotes at the bottom of pages. When a footnote is read, it disrupts the reader's flow; when it is ignored, its point is missed. Integrate the material into the text or appendices to minimise disruption (perhaps in shortened form), or drop it. The same applies to endnotes, which are deferred footnotes or ultrashort appendices. This advice is specific to science writing.

- don't use - integrate into text or drop entirely

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STRUCTURES OF OTHER TYPES OF SCIENCE WRITING

We now run through the structures of other types of science writing,

treating all except books as deviations from the structure set out above for a research paper. Extended review papers share the standard structure, and might include, after the Introduction, a glossary of the symbols used. Overview papers have the standard structure. Summaries to workers outside the specialist area, and to non-scientists, often appear with *no* sections, having at most some one- or two-word guides to what is coming next interposed in bold between paragraphs; write these guides yourself or the journal editor will make an inferior job of it. Write the early part of the paper as an introduction and the end as a summing-up. After the title there is often a 10-30 word outline before the article proper begins. This is too short to indicate much more than the title does, so make clear your purpose in order to gain the reader's interest most effectively. In summary papers you are often allowed the use of boxes to make subsidiary points; our remarks about appendices apply to these. A paper written for non-scientists seldom includes citations in the text, but often gives a further reading list. Research letters, like summary papers, may have no introductory or concluding section; this is justified when they are really short, but ensure that they have introductory and concluding paragraphs.

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Structure of Books

The unit of a book is the chapter. Because a chapter in a book is typically much longer than a section of a paper, it should be subdivided; as ever, construct the skeleton according to your hierarchy of aims. Chapters should open and close with brief overviews and with material linking to the previous and following chapters. (Sometimes chapters are themselves grouped in named and numbered parts of the book, introducing another level of purpose.)

A book begins with the *preface*, in which you state your overall purpose and explain why the book is needed. It is effective to recount a little of the history of the subject. You may also outline how the book came to be written, and you should thank your helpers. A good preface will also outline the purpose of each chapter, how it fits into the overall scheme, and what previous chapters it directly depends on (to assist browsing). The importance of the preface is enormous: together with the sleeve notes, it is what browsers and potential purchasers will read to see what the book is about. It is also what readers will carry into the text.

If you can persuade a well-known worker in the area to write a *foreword* praising the book, so much the better. (Do not settle for a little-known name, which is worse than none.) The foreword is placed before the preface.

It is useful to summarise in a few pages the basic concepts with which the reader is assumed to be familiar. This *prologue* is designed for reference and is not a tutorial; it should indicate sources from which the knowledge can be learned.

Thereafter you are into the first chapter. This may be introductory or, if you consider the preface already to have introduced the material, it begins the main working.

Some books set out a separate list of references for each chapter, either at the end of chapters, or collected together, chapter by chapter, at the end of the book. This prevents browsing of the

complete set of references, makes the references harder to find, and causes the same item to be detailed more than once when it is referred to in different chapters. However, the end of each chapter is a good place to comment on significant papers to which that chapter has referred.

At the end of the book is an index, whose function is to tell the reader where in the book a subject is mentioned. The index is best made by going through the text, *after* this has been completed and paginated, and tagging every significant appearance of a word or phrase which you wish to include. These are then compiled in alphabetical order. The process can be done electronically or manually. Do not tag every technical word, or every trivial appearance of a word; this will not assist anyone. Include acronyms, and give their expanded versions. Where two entries are closely related, give cross-references. Where appropriate, arrange topics in sub-entries. You may have a separate index for names, or you may combine this with the subject index. All appearances of names of persons should be logged.

A monograph need not contain any questions designed to test the reader's understanding. An advanced textbook might do so, at the end of each chapter; an elementary textbook must have them, and should integrate them with the text. Do not relegate anything but the most routine of results to questions: readers might fail to acquire skills by ignoring the questions, but they should not lose any significant information.

Finally, do not use boxes to segregate information in books. They confuse the eye and interrupt the reader's flow. Integrate all technical information into the text or put it in appendices; defer biographical information about scientists, or comments about notable papers, to ends of chapters.

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WRITING FOR NON-SCIENTIST READERS

The requirement that the author simulate the reader is most demanding here, for this is where the gap between the two is widest. It is very hard for an expert continually to maintain the lay point of view; yet only the expert knows the facts. This is the most demanding form of science writing: fail even briefly to hold both viewpoints, and you will lose the reader - for good. Experts become accustomed to technicalities and fail to see them as such; or they may dismiss an ambiguity using expert information unknown to non-scientists; or egotism in keeping it complicated may creep in. It is therefore vital to get feedback on preliminary versions of the paper from non-experts.

It is also vital to maintain the reader's confidence, which begins lower than in other audiences. Raise it at the start by reassuring the reader that the article is designed for non-experts, and keep it high. For example, if in doubt about whether to make a point you consider obvious, do so: some readers will need it, and the rest will have their confidence boosted by being told something they already know. Many readers turn off because they think they won't be able to follow you, not because they have insufficient background in your speciality (a convenient excuse!) or because they judge the work uninteresting.

Use as few technical terms as you can, and define them explicitly where they first appear; context is not enough. Be selective: some truths are more important than others. It is not necessary to sacrifice

accuracy, only to avoid arguments off the main stem. Prune continually the tree of arguments, while ensuring that its parts remain connected; articles often read well superficially but are found to contain logical jumps on closer reading. Do, however, indicate how to reach obviously related topics which interested non-scientists may have heard of. Accept that you can only go so far: the correct response to a non-scientist requesting more than a certain depth of detail is an invitation to take a formal course. Use figures to illustrate points where you can. Relate quantities to familiar things, for example the sun's power in H-bombs per second. Use plenty of analogies; effective ones are always imagistic and made with things familiar to non-scientists. Make plain the limits of your analogies, or your readers will export them too far.

In popular books, avoid the temptation to abuse your position as an expert on one subject in order to hold forth on others in which you are no better qualified than your readers. (The urge to metaphysics and ethics is notorious.) Even if writing of this sort sells books, it demeans the scientific content of your exposition.

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IMAGERY AND ILLUSTRATIONS

IMAGERY. Vision has a deep connection with thought, revealed in language: *imagine*; "I see" (meaning I *understand*); *envisage*; "picture this". Imagery is part of both private thinking (of which writing is a part) and public expository writing. It is vital in revealing structure. Some classic examples from science are molecular structure diagrams in organic chemistry, and Feynman diagrams in physics. If you have a picture in mind, use words - nouns, verbs, adjectives - that conjure up pictures. Many scientific terms began as analogies with everyday usage, and these are particularly helpful. Analogy engages the imagination.

ILLUSTRATIONS. An illustration is useful when it makes it significantly easier for the reader to take the writer's point than from words alone. Many diagrams - maps, for example - present large amounts of information to the reader in a form the eye and brain has evolved to understand very rapidly. Illustration is effective because imagery is part of thought. An illustration is a pictorial representation of information, often a very compact one. Illustrations catch the eye; they are often looked at first, and so they should have self-explanatory captions and be placed as soon as is possible after that part of the text which refers to them. (Figures *illuminate* text - they cannot stand alone.) Each illustration should make a single point; to make a second point, use a second illustration - even if it looks similar to the first. It has a different purpose.

Tables are useful when *comparison* is to be done; for example, tables of car prices and performance parameters in motoring magazines. There is an art to deciding when to segregate information in tables by horizontal and vertical lines; for details of this, and finer details of constructing graphs, read Chapter 10 of the book by Turk & Kirkman, and the book by Tufte (see bibliography; there are many other books on diagrammatics).

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TIPS FOR WRITING

These tips are more piecemeal than the previous material. They are not meant to be learned exhaustively, but practice in comparing your writing with them ("post-mortem analysis"), followed by rewriting, will help you learn. SCITEXT's writing [courses](#) are designed to help scientists assimilate them.

EXPLANATION AND FLOW

The flow of the paper must be kept even: there is an optimal rate to impart information. Too slow and the reader is bored (rare in papers); too fast (as in many letters journals) and the reader becomes dizzy. Too uneven and the reader confuses major and minor points, so allocate the appropriate amount of explanation to every point. Papers are ruined by over-explanation as well as by under-explanation. The most common cause of under-explanation is failure to finish an explanation, or tailing off - perhaps because "it's obvious from here", but not to the first-time reader. Over-explanation is caused by excessive zeal and is a hangover from the writer's own learning of the material. An example is unwitting tautology - saying the same thing twice, rather than developing it (see Barrass, table 10, p60). If for emphasis you repeat a point, with differing phraseology, make it plain that you are repeating; otherwise the reader will fail to detect any difference but still believe there is one, and become confused. Make sure a point sticks by locating and anchoring it in its proper place in the logical structure of the paper; anchoring means relating it to what goes before and after it. For non-trivial points, state explicitly how important they are. The book by Kapp (in the bibliography below) is good on the rate of flow in a paper. At the level of individual sentences, punctuation is a rate-determinant.

Maintain the reader's interest. You can cause it to be generated, by creating the desire to know for example, so that the reader feels satisfaction at the answer. Techniques for doing this include writing as a joint search after truth, or posing and answering questions; questions emphasise mystery and heighten drama. (Questions may be put in the form "We now ask: ...") You may also set out what were possibilities according to the previous state of knowledge, then stating which is correct and why using the new knowledge you are imparting. These techniques are useful at transitions between sections (where your purpose changes).

The principle that the start and end of a paper are more important generally applies at the smaller scale. In a long paragraph it is often worth explaining (in advance) what you're doing and why you're doing it. The hierarchy of purposes extends down to paragraphs; after each paragraph, ask yourself if you've achieved your immediate purpose. This principle applies even to sentences; if, for example, you are recapitulating, beginning the sentence with a phrase like "In short..." will prepare the reader.

Make your writing *sequentially comprehensible*. Otherwise, it is not understandable in a single pass and the reader must go back and forth; flow and authority are lost. For the flow of logic, this is done by writing teleologically; for the flow of words it is done by making sure that every sentence is sequentially comprehensible; then every paragraph; and so on. Minimise referrals ahead (except in the Introduction) and keep track of them; never refer ahead implicitly.

Readers *parse* sentences - resolve them by rules of grammar into their component parts - so make this process easy. Qualified assertions are common in technical exposition: if the qualification follows after, mental revision is necessary and the flow is interrupted,

so put it first ("Provided that...") Cut out superfluous qualification (for examples see Barrass, table 11, p61).

AMBIGUITY

Always avoid ambiguity. Ambiguity may be introduced accidentally and never resolved, in which case readers have to resolve it for themselves or remain confused; or it may be resolved soon after (often earlier and later in the same sentence), in which case the reader has to jump back, disrupting the flow. Lurking ambiguity is a common cause if a sentence jars on reading. It is particularly difficult to spot your own ambiguities, since authors tend to see what they mean in their pieces rather than what they say; this is a strong reason why others should read your paper before submission.

Words having more than one meaning are usually unambiguous in context; ensure the context is a familiar one to readers.

VOICE

Writing may take place in the first person singular ("I...") and plural ("We...") and occasionally in the third person ("The writer..."); or as an address, to the second person ("If you now...") or the third ("The reader will now see..."); finally, as the imperative ("Now eliminate the velocity from these equations") or the passive ("The velocity is now eliminated..."). "We" is always acceptable in multiple-author papers, and in single-author papers if it can be taken to mean "the writer plus the reader"; otherwise it signifies loftiness or avoidance of responsibility by the author. "I" is often deemed too personal (strangely, since "we" is acceptable to mean "the authors"), which is why the diffident third person is occasionally found. Authorial attempts to avoid commitment like these and in phrases such as "seems", "may or may not", will instantly be detected by the reader; if the author doesn't have confidence in the material, how can the reader? Where you are speculating, use only *one* speculation-word per sentence. The passive voice is always acceptable, but do not use it incessantly, and avoid "It is to be hoped that...", because hope is a human item and use of the passive is deliberately inhuman. Do not use the passive voice to avoid responsibility, as in "It is conjectured that..." - by whom? You should not cover the subjective with a veneer of the objective.

Whether the active or passive voice should be used in, for example, "the wire carries the current" or "the current is carried by the wire", depends on where you want to place emphasis. In the first it is on the wire, in the second on the current.

The use of "you" to address the reader, or the imperative voice for advice like "do not...", is closer to spoken language, but is still not the same as spoken style transcribed. Spoken style uses words to separate ideas instead of paragraph breaks, and repeats material more often to give the listener, who cannot now jump back if confused, time to grasp the ideas.

For emphasis, use italics (or bold, or underlining) or single inverted commas. It is emphatic to start a sentence with "And..." or "But..." Emphasis should mostly spring naturally from sentence structure and meaning, and is therefore easily overdone. Use as much emphasis as you like in the first draft and then prune it heavily. In general, italicise only single words; only very rarely whole phrases.

GENERAL POINTS OF STYLE

If something remains unclear, say so clearly; do not lapse into a lofty or mystical style to make the point. If you are speculating, say so. Beware of wish-fulfilment: do not lower your standards of reasoning where you want something to be true but aren't certain of it. Never be deliberately subtle; subtle nuances reflect the way *you* think on the fine scale, but people differ widely and these nuances will not be picked up by others.

Beware of egotistical writing. In particular, prefer understatement to overstatement, which will turn the reader against you.

In deciding whether to use the general or the specific, begin with the specific if the general can be grasped only after thought, and begin with the general if that is immediately comprehensible, and then bring out specific consequences [Kapp, chapter 11]. In going from the general to the specific, choose cases that are representative, simple and telling. If possible, use a graded series of examples.

Write as concretely as you can. Woodford (p49; see the bibliography below) points out that action is too often relegated from its proper place in verbs; for example, "the separation of A from B was effected" instead of "A was separated from B". Many books on science writing have useful lists of weak words or phrases, or words that warn something has gone wrong. These lists should not be learned verbatim, but their motivation should be taken to heart.

Remember that you are writing for a worldwide audience, not all having English as first language. Because of its hybrid origins, English often has a wider choice of words for something, differing in overtones. These overtones will not be picked up non-native English speakers, so be as expressive as you need but never more so.

Maintain consistent conventions throughout. For example, if you hyphenate a word (eg *non-linear*), do not later run the two halves together (*nonlinear*).

SENTENCE CONSTRUCTION

Sentence construction is flexible enough to be recognisably personal. Therefore, like personality, it is beyond full encapsulation in a set of rules, and remains a craft which must be learned by exposure to examples together with guided tuition. The principles below should be seen in that context. They are based on experience and are not systematic.

Necessary for a sentence to read well is that it shall be comprehensible in a single pass, from the beginning to the end with no logical jumps back. In English sentences there is great flexibility in the order of clauses: exploit this. If a sentence is clumsy, try re-ordering it (which may alter emphases) or repunctuating it, or moving the full stops [periods]: for example, you may split it in two, or merge it with the previous or following sentences.

It is not long sentences which confuse, but ones with complicated structure. Nevertheless, scientists who are not expert in English can best avoid ambiguity or other trouble by keeping sentences short. Non-native English speakers should also study when to use the definite article ("the"), the indefinite article "a[n]"), or neither. Be sure to choose the correct prepositions; wrong choices distort meaning very rapidly.

Phrases in a sentence may be separated by punctuation marks

(commas, semi-colons, colons, dashes, brackets) or linking words (such as *and*, *but*). The semi-colon is under-rated in scientific exposition. For punctuation, please refer to one of the many good books available. Linking words may also continue the flow across sentences; when a new sentence begins with *however*, *moreover*, *next*, *therefore*, *also*, for example.

Be tight about what the word "this" (or "it") refers to; slackness is a common disrupter of flow or cause of ambiguity. It may help to repeat explicitly the thing being referred to. The word "this" is also a "sticky" word: it jars if used in successive sentences.

Vary the rhythm of sentences, by avoiding over-repetition of the patterns of sentence construction. These patterns have been analysed in great detail: see the invaluable book by Corbett in the bibliography below. Barrass gives a short list of common uglinesses (p83-4) and Alley some helpful advice ("Being fluid").

BIBLIOGRAPHY

There are many books and essays on English grammar and style, and on the writing of technical and non-technical reports. This list includes those which we think most useful to working scientists and those which are most likely to be easily accessible. Writers should have a good dictionary and thesaurus at hand, and an authoritative guide to modern English usage; their combined cost is under half that of many academic textbooks. Non-native English speakers need also a book of English grammar. Although we list some on-line documents, books are both easier and faster to browse; the power of the Web lies in interconnectivity between documents rather than presentation of individual documents.

Prices are approximate; these and the ISBN are quoted for paperback versions if available. You can order books worldwide from the on-line bookselling service [Amazon.com](http://www.amazon.com) or for out-of-print books try [Bookfinder](http://www.bookfinder.com).

The Elements of Style. W. Strunk Jr. and E.B. White. 3rd edition published by Allyn and Bacon, 1979. 92pp. ISBN 0-205-19158-4. #5. A standard for many decades. It remains up-to-date and has the merit of brevity. [An on-line version of this book is available here](#).

The Complete Plain Words. Ernest Gowers. 3rd edition published by Pelican, 1987. 288pp. ISBN 0-14-051199-7. #8. Another classic on how to write good English.

Good Style: Writing for Science and Technology. John Kirkman. Published by E. & F.N. Spon, 1992. 221pp. ISBN 0-419-17190-8. #12.50. Concerned with issues of writing style, not document structure.

Effective Writing: Improving Scientific, Technical and Business Communication. Christopher Turk and John Kirkman. 2nd edition published by E. & F.N. Spon, 1989. 277pp. ISBN 0-419-14660-1. #13. Deals with informative writing of all types. Good on graphics.

Writing for Results in Business, Government, the Sciences, the Professions. David W. Ewing. 2nd edition published by Wiley, 1979. 448pp. ISBN 0-471-05036-9. Out of print. A good book which does not seek to reduce writing to rigid rules.

The Scientist's Handbook for Writing Papers and Dissertations.

Antoinette M. Wilkinson. Published by Prentice-Hall, 1991. 522pp. ISBN 0-13-969411-0. #44. Too long to learn effectively from, but a good systematic reference book.

The Craft of Scientific Writing. Michael Alley. 3rd edition published by Springer, 1996. 282pp. ISBN 0-387-94766-3. #18.50. Gets to grips with the less tangible elements of expository style very well indeed.

A Guide to Scientific Writing. David Lindsay. 2nd edition published by Longman, 1995. 126pp. ISBN 0-582-80312-8. #8. Concise and thoughtful, with good tips throughout.

The Presentation of Technical Information. R.O. Kapp. 2nd edition published by Constable, 1973. 184pp. ISBN 0-09-459070-2. Out of print. A thoughtful book which explains to writers how their work is perceived by readers.

Scientists Must Write. Robert Barrass. Published by Chapman & Hall, 1978. 176pp. ISBN 0-412-15430-7. #11. Deals with informative writing for scientists. Like Alley, a fine "ideas" book which does not stifle with rules.

Scientific Writing For Graduate Students. F.P. Woodford (editor and principal author). Published by MacMillan, 1968. 190pp. Out of print. Subtitled *A Manual on the Teaching of Scientific Writing*. Woodford believes that scientists should be taught, by scientists, a full course in science writing when graduate students; we agree. All science writers would benefit from reading the extended tutorial examples of corrected text contained in this book. Unfortunately you will now find it only in reference libraries.

Principles of Scientific and Technical Writing. Jackson E. Morris. Published by McGraw-Hill, 1966. 257pp. Out of print. A deep piece of writing which unerringly addresses the central issues, and is excellent on the greatest problem of written style - sentence construction.

Mathematical Writing. Donald E. Knuth, T. Larrabee and P.M. Roberts. Published by the Mathematical Association of America, 1989. 115pp. ISBN 0-88385-063-X. #10. Includes an utterly remarkable (and exhausting) set of do-it-yourself exercises for improving your writing, by Mary-Claire van Leunen, an editor and textbook writer. The rest of this book is a useful if idiosyncratic guide.

Bugs in Writing: A Guide to Debugging Your Prose. Lyn Dupré. Revised edition published by Addison-Wesley, 1998. 668pp. ISBN 0-201-37921-X. #15. The author, an experienced editor of scientific manuscripts, discusses common inelegancies she has found and how to avoid them, with the aim of equipping readers to discern good style for themselves. Good if you can bear the author's self-indulgence.

Copy-Editing: The Cambridge Handbook for Editors, Authors and Publishers. Judith Butcher. 3rd edition published by Cambridge University Press, 1992. 471pp. ISBN 0-521-40074-0. #25. Tells you what happens to your preprint once it has been accepted; information which, known in advance, will assist in your partnership with any publisher.

The ACS Style Guide. Janet S. Dodd (editor). Published by the American Chemical Society, 1986. 264pp. ISBN 0-8412-0943-X. #14. Contains a long section on style, and further material concerning a standard format for a large group of journals in one particular discipline. There are several other such "umbrella" handbooks.

The Visual Display of Quantitative Information. Edward R. Tufte. Published by Graphics Press, Connecticut, U.S.A., 1983. 197pp. ISBN 0-9613921-0-X. \$40. Easily the farthest-sighted study of statistical graphics, packed with examples and explanations of what makes good (and bad) graphics and visualisations. Tufte has written other books, *Envisioning Information* and *Visual Explanations*, which treat the imaging of information not explicitly phrased in numerical form.

Classical Rhetoric for the Modern Student. E.P.J. Corbett and R.J. Connors. 4th edition published by Oxford University Press, 1999. 562pp. ISBN 0-19-511542-2. #28.50. The long section of this book concerned with style is the best self-help reading we know of for improving your own writing. It shows that style *can* be analysed (and hence learned), by identifying and discussing the various devices used in prose writing; these were first uncovered in the ancient world. Includes analyses of extended pieces of text.

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