**WRITING A SCIENTIFIC RESEARCH ARTICLE**

Scientific research articles provide a method for scientists to communicate with other scientists about the results of their research. A standard format is used for these articles, in which the author presents the research in an orderly, logical manner. This doesn't necessarily reflect the order in which you did or thought about the work.  This format is:

**TITLE**

1. Make your title specific enough to describe the contents of the paper, but not so technical that only specialists will understand. The title should be appropriate for the intended audience.
2. The title usually describes the subject matter of the article: Effect of Smoking on Academic Performance"
3. Sometimes a title that summarizes the results is more effective: Students Who Smoke Get Lower Grades"

**AUTHORS**

1. The person who did the work and wrote the paper is generally listed as the first author of a research paper.

2. For published articles, other people who made substantial contributions to the work are also listed as authors. Ask your mentor's permission before including his/her name as co-author.

**ABSTRACT**

1. An abstract, or summary, is published together with a research article, giving the reader a "preview" of what's to come. Such abstracts may also be published separately in bibliographical sources, such as Biologic al Abstracts. They allow other scientists to quickly scan the large scientific literature, and decide which articles they want to read in depth. The abstract should be a little less technical than the article itself; you don't want to dissuade your potent ial audience from reading your paper.

2. Your abstract should be one paragraph, of 100-250 words, which summarizes the purpose, methods, results and conclusions of the paper.

3. It is not easy to include all this information in just a few words. Start by writing a summary that includes whatever you think is important, and then gradually prune it down to size by removing unnecessary words, while still retaini ng the necessary concepts.

3. Don't use abbreviations or citations in the abstract. It should be able to stand alone without any footnotes.

**INTRODUCTION**

What question did you ask in your experiment? Why is it interesting? The introduction summarizes the relevant literature so that the reader will understand why you were interested in the question you asked. One to fo ur paragraphs should be enough. End with a sentence explaining the specific question you asked in this experiment.

**MATERIALS AND METHODS**

1. How did you answer this question? There should be enough information here to allow another scientist to repeat your experiment. Look at other papers that have been published in your field to get some idea of what is included in this section.

2. If you had a complicated protocol, it may helpful to include a diagram, table or flowchart to explain the methods you used.

3. Do not put results in this section. You may, however, include preliminary results that were used to design the main experiment that you are reporting on. ("In a preliminary study, I observed the owls for one week, and found that 73 % of their locomotor activity occurred during the night, and so I conducted all subsequent experiments between 11 pm and 6 am.")

4. Mention relevant ethical considerations. If you used human subjects, did they consent to participate. If you used animals, what measures did you take to minimize pain?

**RESULTS**

1. This is where you present the results you've gotten. Use graphs and tables if appropriate, but also summarize your main findings in the text. Do NOT discuss the results or speculate as to why something happened; t hat goes in th e Discussion.

2. You don't necessarily have to include all the data you've gotten during the semester. This isn't a diary.

3. Use appropriate methods of showing data. Don't try to manipulate the data to make it look like you did more than you actually did.

*"The drug cured 1/3 of the infected mice, another 1/3 were not affected, and the third mouse got away."*

**TABLES AND GRAPHS**

1. If you present your data in a table or graph, include a title describing what's in the table ("Enzyme activity at various temperatures", not "My results".) For graphs, you should also label the x and y axes.

2. Don't use a table or graph just to be "fancy". If you can summarize the information in one sentence, then a table or graph is not necessary.

**DISCUSSION**

1. Highlight the most significant results, but don't just repeat what you've written in the Results section. How do these results relate to the original question? Do the data support your hypothesis? Are your results consistent with what other investigators have reported? If your results were unexpected, try to explain why. Is there another way to interpret your results? What further research would be necessary to answer the questions raised by your results? How do y our results fit into the big picture?

2. End with a one-sentence summary of your conclusion, emphasizing why it is relevant.

**ACKNOWLEDGMENTS**

This section is optional. You can thank those who either helped with the experiments, or made other important contributions, such as discussing the protocol, commenting on the manuscript, or buying you pizza.

**REFERENCES (LITERATURE CITED)**

There are several possible ways to organize this section. Here is one commonly used way:

1. In the text, cite the literature in the appropriate places:

Scarlet (1990) thought that the gene was present only in yeast, but it has since been identified in the platypus (Indigo and Mauve, 1994) and wombat (Magenta, et al., 1995).

2. In the References section list citations in alphabetical order.

Indigo, A. C., and Mauve, B. E. 1994. Queer place for qwerty: gene isolation from the platypus. Science 275, 1213-1214.

Magenta, S. T., Sepia, X., and Turquoise, U. 1995. Wombat genetics. In: Widiculous Wombats, Violet, Q., ed. New York: Columbia University Press. p 123-145.

Scarlet, S.L. 1990. Isolation of qwerty gene from S. cerevisae. Journal of Unusual Results 36, 26-31.

**EDIT YOUR PAPER!!!**

|  |
| --- |
| "In my writing, I average about ten pages a day. Unfortunately, they're all the same page."  Michael Alley, The Craft of Scientific Writing |

A major part of any writing assignment consists of re-writing.

Write accurately

1. Scientific writing must be accurate. Although writing instructors may tell you not to use the same word twice in a sentence, it's okay for scientific writing, which must be accurate. (A student who tried not to repeat the word "hamster" produced this confusing sentence: "When I put the hamster in a cage with the other animals, the little mammals began to play.")
2. Make sure you say what you mean.

*Instead of:* The rats were injected with the drug. (sounds like a syringe was filled with drug and ground-up rats and both were injected together)  
*Write:* I injected the drug into the rat.

1. Be careful with commonly confused words:

Temperature has an *effect* on the reaction.

Temperature *affects* the reaction.

I used solutions in various concentrations. (The solutions were 5 mg/ml, 10 mg/ml, and 15 mg/ml)  
I used solutions in varying concentrations. (The concentrations I used changed; sometimes they were 5 mg/ml, other times they were 15 mg/ml.)

 Less food (can't count numbers of food)

Fewer animals (can count numbers of animals)

A large amount of food (can't count them)

A large number of animals (can count them)

The erythrocytes, which are in the blood, contain hemoglobin.

The erythrocytes that are in the blood contain hemoglobin. (Wrong. This sentence implies that there are erythrocytes elsewhere that don't contain hemoglobin.)

Write clearly

1. Write at a level that's appropriate for your audience.

"Like a pigeon, something to admire as long as it isn't over your head." Anonymous

 2. Use the active voice. It's clearer and more concise than the passive voice.

 Instead of: An increased appetite was manifested by the rats and an increase in body weight was measured.  
Write: The rats ate more and gained weight.

 3. Use the first person.

 Instead of: It is thought

Write: I think

 Instead of: The samples were analyzed

Write: I analyzed the samples

 4. Avoid dangling participles.

 "After incubating at 30 degrees C, we examined the petri plates." (You must've been pretty warm in there.)

 Write succinctly

 1. Use verbs instead of abstract nouns

 Instead of: take into consideration

Write: consider

 2. Use strong verbs instead of "to be"

 Instead of: The enzyme was found to be the active agent in catalyzing...  
Write: The enzyme catalyzed...

 3. Use short words.

|  |  |
| --- | --- |
| **Instead of:** | **Write:** |
| prior to | before |
| due to the fact that | because |
| in a considerable number of cases | often |
| the vast majority of | most |
| during the time that | when |
| in close proximity to | near |
| it has long been known that | I'm too lazy to look up the reference |

|  |  |
| --- | --- |
| **Instead of:** | **Write:** |
| possess | have |
| sufficient | enough |
| utilize | use |
| demonstrate | show |
| assistance | help |
| terminate | end |

4. Use concise terms.

5. Use short sentences. A sentence made of more than 40 words should probably be rewritten as two sentences.

 "The conjunction 'and' commonly serves to indicate that the writer's mind still functions even when no signs of the phenomenon are noticeable." Rudolf Virchow, 1928

 Check your grammar, spelling and punctuation

1. Use a spellchecker, but be aware that they don't catch all mistakes.

 "When we consider the animal as a hole,..." Student's paper

 2. Your spellchecker may not recognize scientific terms. For the correct spelling, try [Biotech's Life Science Dictionary](http://biotech.icmb.utexas.edu/search/dict-search.html) or one of the technical dictionaries on the reference shelf in the Biology or Health Sciences libraries.

 3. Don't, use, unnecessary, commas.

 4. Proofread carefully to see if you any words out.

**A GUIDE TO WRITING SCIENTIFIC PAPERS**

Scientific experiments are demanding, exciting endeavors, but, to have an impact, results must be communicated to others. A research paper is a method of communication, an attempt to tell others about some specific data that you have gathered and what you think those data mean in the context of your research. The "rules" of writing a scientific paper are rigid and are different from those that apply when you write an English theme or a library research paper. For clear communication, the paper obviously requires proper usage of the English language and this will be considered in evaluating your reports. Scientific papers must be written clearly and concisely so that readers with backgrounds similar to yours can understand easily what you have done and how you have done it should they want to repeat or extend your work. When writing papers for the biology department, you can assume that your audience will be readers like yourselves with similar knowledge.

Although scientific journals differ somewhat in their specific requirements, a general format that would be acceptable for most biological journals is:

Title, Abstract, Introduction, Materials and Methods, Results, Discussion, Conclusions, Acknowledgments , iterature Cited

The section headings (Abstract, Introduction, etc.) should be **centered** and the body of each section should follow immediately below the heading. Do not begin each section on a new page. If one section ends part of the way down the page, the next section heading follows immediately on the same page.

One important general rule to keep in mind is that a scientific paper is a report about something that has been done in the past. Most of the paper should be written in the **PAST TENSE** (was, were). The present tense (is, are) is used when stating generalizations or conclusions. The present tense is most often used in the Introduction, Discussion and Conclusion sections of papers. The paper should read as a narrative in which the author describes what was done and what results were obtained from that work.

**TITLE**

Every scientific paper must have a self-explanatory title. By reading the title, the work being reported should be clear to the reader without having to read the paper itself. The title, "A Biology Lab Report", tells the reader nothing. An example of a good, self-explanatory title would be: "The Effects of Light and Temperature on the Growth of Populations of the Bacterium, *Escherichia coli* ". This title reports exactly what the researcher has done by stating three things:

1. The environmental factors that were manipulated (light, temperature).

2. The parameter that was measured (growth).

3. The specific organism that was studied (the bacterium, *Escherichia coli*).

If the title had been only "Effects of Light and Temperature on *Escherichia coli* ", the reader would have to guess which parameters were measured. (That is, were the effects on reproduction, survival, dry weight or something else?) If the title had been "Effect of Environmental Factors on Growth of *Escherichia coli* ", the reader would not know which environmental factors were manipulated. If the title had been "Effects of Light and Temperature on the Growth of an Organism", then the reader would not know which organism was studied. In any of the above cases, the reader would be forced to read more of the paper to understand what the researcher had done.

Exceptions do occur: If several factors were manipulated, all of them do not have to be listed. Instead, "Effects of Several Environmental Factors on Growth of Populations of*Escherichia coli* " (if more than two or three factors were manipulated) would be appropriate. The same applies if more than two or three organisms were studied. For example, "Effects of Light and Temperature on the Growth of Four Species of Bacteria" would be correct. The researcher would then include the names of the bacteria in the Materials and Methods section of the paper.

**ABSTRACT**

The abstract section in a scientific paper is a concise digest of the content of the paper. An abstract is more than a summary. A summary is a brief restatement of preceding text that is intended to orient a reader who has studied the preceding text. An abstract is intended to be self-explanatory without reference to the paper, but is not a substitute for the paper.

The abstract should present, in about 250 words, the purpose of the paper, general materials and methods (including, if any, the scientific and common names of organisms), summarized results, and the major conclusions. Do not include any information that is not contained in the body of the paper. Exclude **detailed** descriptions of organisms, materials and methods. Tables or figures, references to tables or figures, or references to literature cited usually are not included in this section. The abstract is usually written last. An easy way to write the abstract is to extract the most important points from each section of the paper and then use those points to construct a brief description of your study.

**INTRODUCTION**

The Introduction is the statement of the problem that you investigated. It should give readers enough information to appreciate your specific objectives within a larger theoretical framework. After placing your work in a broader context, you should state the specific question(s) to be answered. This section may also include background information about the problem such as a summary of any research that has been done on the problem in the past and how the present experiment will help to clarify or expand the knowledge in this general area. All background information gathered from other sources must, of course, be appropriately cited. (Proper citation of references will be described later.)

A helpful strategy in this section is to go from the general, theoretical framework to your specific question. However, do not make the Introduction *too* broad. Remember that you are writing for classmates who have knowledge similar to yours. Present only the most relevant ideas and get quickly to the point of the paper. **For examples, see the Appendix**.

**MATERIALS AND METHODS**

This section explains how and, where relevant, when the experiment was done. The researcher describes the experimental design, the apparatus, methods of gathering data and type of control. If any work was done in a natural habitat, the worker describes the study area, states its location and explains when the work was done. If specimens were collected for study, where and when that material was collected are stated. The general rule to remember is that the Materials and Methods section should be detailed and clear enough so that any reader knowledgeable in basic scientific techniques could duplicate the study if she/he wished to do so. **For examples, see the Appendix**.

**DO NOT** write this section as though it were directions in a laboratory exercise book. Instead of writing:

First pour agar into six petri plates. Then inoculate the plates with the bacteria. Then put the plates into the incubator . . .

Simply describe how the experiment was done:

Six petri plates were prepared with agar and inoculated with the bacteria. The plates were incubated for ten hours.

Also, **DO NOT LIST** the equipment used in the experiment. The materials that were used in the research are simply mentioned in the narrative as the experimental procedure is described in detail. If well-known methods were used without changes, simply name the methods (e.g., standard microscopic techniques; standard spectrophotometric techniques). If modified standard techniques were used, describe the changes.

**RESULTS**

Here the researcher presents **summarized** data for inspection **using narrative text** and, where appropriate, tables and figures to display summarized data. Only the results are presented. No interpretation of the data or conclusions about what the data might mean are given in this section. Data assembled in tables and/or figures should **supplement** the text and present the data in an easily understandable form. **Do not present raw data!** If tables and/or figures are used, **they must be accompanied by narrative text**. Do not repeat extensively in the text the data you have presented in tables and figures. But, do not restrict yourself to passing comments either. (For example, only stating that "Results are shown in Table 1." is not appropriate.) The text **describes** the data presented in the tables and figures and calls attention to the important data that the researcher will discuss in the Discussion section and will use to support Conclusions. (Rules to follow when constructing and presenting figures and tables are presented in a later section of this guide.)

**DISCUSSION**

Here, the researcher **interprets** the data in terms of any patterns that were observed, any relationships among experimental variables that are important and any correlations between variables that are discernible. The author should include any explanations of how the results differed from those hypothesized, or how the results were either different from or similar to those of any related experiments performed by other researchers. Remember that experiments do not always need to show major differences or trends to be important. "Negative" results also need to be explained and may represent something important--perhaps a new or changed focus for your research.

A useful strategy in discussing your experiment is to relate your specific results back to the broad theoretical context presented in the Introduction. Since your Introduction went from the general to a specific question, going from the specific back to the general will help to tie your ideas and arguments together.

**CONCLUSIONS**

This section simply states what the researcher thinks the data mean, and, as such, should relate directly back to the problem/question stated in the introduction. This section should not offer any *reasons* for those particular conclusions--these should have been presented in the Discussion section. By looking at only the Introduction and Conclusions sections, a reader should have a good idea of what the researcher has investigated and discovered even though the specific details of how the work was done would not be known.

**ACKNOWLEDGEMENTS**

In this section you should give credit to people who have helped you with the research or with writing the paper. If your work has been supported by a grant, you would also give credit for that in this section.

**LITERATURE CITED**

This section lists, in alphabetical order by author, all published information that was referred to anywhere in the text of the paper. It provides the readers with the information needed should they want to refer to the original literature on the general problem. Note that the Literature Cited section includes only those references that were **actually mentioned** (cited) in the paper. Any other information that the researcher may have read about the problem but did **not** mention in the paper is **not** included in this section. This is why the section is called "Literature Cited" instead of "References" or "Bibliography".

The system of citing reference material in scientific journals varies with the particular journal. The method that you will follow is the "author-date" system. Listed below are several examples of how citations should be presented in the text of your paper. The name(s) of the author(s) and year of publication are included in the body of the text. Sentence structure determines the placement of the parentheses.

**One author**: 'Scott's (1990) model fails to ...' or 'The stream model (Scott 1990) is ...'

**Two authors**: 'Libby and Libby (1991) show...' or 'Previous moose migration studies (Libby and Libby 1991)...'

**Three or more authors**: 'Roche *et al.* (1991) reported that ...' or 'During April, moose sightings increased over those in a previous study (Roche *et al.* 1991) .....'

Entries in the Literature Cited section are listed alphabetically by author(s) and chronologically for papers by the same author(s). The following citations illustrate the details of punctuation and order of information for a journal article, book, Internet source, and your laboratory packet.

Schneider, M.J., Troxler, R.F. and Voth, P.D. 1967. Occurrence of indoleacetic acid in the bryophytes. Bot. Gaz. 28(3): 174-179.

Stebbins, G.L. 1977. Processes of Organic Evolution. Prentice-Hall, New Jersey. 269 pp.

MSW Scientific Names: Microtus ochrogaster. Online. Smithsonian Institution. Available: http://www.nmnh.si.edu/cgi-bin/wdb/msw/names/query/22128. updated August 8, 1996 [accessed 8/10/98]

Colby Biology Department. 1998. Salt Tolerance in *Phaseolus vulgaris.* In: Introduction to Biology: Organismal Biology. Waterville, ME: Colby Custom Publishing

Generally, most references will be to the primary literature (i.e., journal articles) and, to a lesser extent, books. Popular literature and the Internet should be used sparingly and with caution. Other sources such as book chapters and pamphlets typically have their own specific citation formats. If necessary, be sure to find out what these formats are and use them appropriately.

For a much more detailed discussion about writing scientific papers, consult: CBE Style Manual Committee. 1983. *CBE Style Manual: A Guide for Authors, Editors and Publishers in the Biological Sciences*. 5th Edition, revised and expanded. Council of Biology Editors, Inc., Bethesda, Maryland.

**APPENDIX**

Examples from the scientific literature that illustrate material in various sections of a scientific paper.

# How to Write Your First Research Paper

## Abstract

Writing a research manuscript is an intimidating process for many novice writers in the sciences. One of the stumbling blocks is the beginning of the process and creating the first draft. This paper presents guidelines on how to initiate the writing process and draft each section of a research manuscript. The paper discusses seven rules that allow the writer to prepare a well-structured and comprehensive manuscript for a publication submission. In addition, the author lists different strategies for successful revision. Each of those strategies represents a step in the revision process and should help the writer improve the quality of the manuscript. The paper could be considered a brief manual for publication.

**Keywords:** scientific paper, writing process, revision

It is late at night. You have been struggling with your project for a year. You generated an enormous amount of interesting data. Your pipette feels like an extension of your hand, and running western blots has become part of your daily routine, similar to brushing your teeth. Your colleagues think you are ready to write a paper, and your lab mates tease you about your “slow” writing progress. Yet days pass, and you cannot force yourself to sit down to write. You have not written anything for a while (lab reports do not count), and you feel you have lost your stamina. How does the writing process work? How can you fit your writing into a daily schedule packed with experiments? What section should you start with? What distinguishes a good research paper from a bad one? How should you revise your paper? These and many other questions buzz in your head and keep you stressed. As a result, you procrastinate. In this paper, I will discuss the issues related to the writing process of a scientific paper. Specifically, I will focus on the best approaches to start a scientific paper, tips for writing each section, and the best revision strategies.

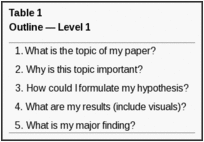
## 1. Schedule your writing time in Outlook

Whether you have written 100 papers or you are struggling with your first, starting the process is the most difficult part unless you have a rigid writing schedule. Writing is hard. It is a very difficult process of intense concentration and brain work. As stated in Hayes’ framework for the study of writing: “It is a generative activity requiring motivation, and it is an intellectual activity requiring cognitive processes and memory” [[1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R1)]. In his book How to Write a Lot: A Practical Guide to Productive Academic Writing, Paul Silvia says that for some, “it’s easier to embalm the dead than to write an article about it” [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R2)]. Just as with any type of hard work, you will not succeed unless you practice regularly. If you have not done physical exercises for a year, only regular workouts can get you into good shape again. The same kind of regular exercises, or I call them “writing sessions,” are required to be a productive author. Choose from 1- to 2-hour blocks in your daily work schedule and consider them as non-cancellable appointments. When figuring out which blocks of time will be set for writing, you should select the time that works best for this type of work. For many people, mornings are more productive. One Yale University graduate student spent a semester writing from 8 a.m. to 9 a.m. when her lab was empty. At the end of the semester, she was amazed at how much she accomplished without even interrupting her regular lab hours. In addition, doing the hardest task first thing in the morning contributes to the sense of accomplishment during the rest of the day. This positive feeling spills over into our work and life and has a very positive effect on our overall attitude.

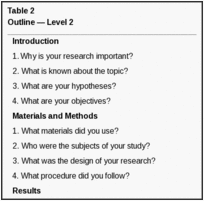
### Rule 1: Create regular time blocks for writing as appointments in your calendar and keep these appointments.

## 2. Start with an outline

Now that you have scheduled time, you need to decide how to start writing. The best strategy is to start with an outline. This will not be an outline that you are used to, with Roman numerals for each section and neat parallel listing of topic sentences and supporting points. This outline will be similar to a template for your paper. Initially, the outline will form a structure for your paper; it will help generate ideas and formulate hypotheses. Following the advice of George M. Whitesides, “. . . start with a blank piece of paper, and write down, in any order, all important ideas that occur to you concerning the paper” [[3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R3)]. Use [Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T1/) as a starting point for your outline. Include your visuals (figures, tables, formulas, equations, and algorithms), and list your findings. These will constitute the first level of your outline, which will eventually expand as you elaborate.

[](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T1/)

**Outline — Level 1**

[](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T2/)The next stage is to add context and structure. Here you will group all your ideas into sections: Introduction, Methods, Results, and Discussion/Conclusion ([Table 2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T2/)). This step will help add coherence to your work and sift your ideas.

**Outline — Level 2**

Now that you have expanded your outline, you are ready for the next step: discussing the ideas for your paper with your colleagues and mentor. Many universities have a writing center where graduate students can schedule individual consultations and receive assistance with their paper drafts. Getting feedback during early stages of your draft can save a lot of time. Talking through ideas allows people to conceptualize and organize thoughts to find their direction without wasting time on unnecessary writing. Outlining is the most effective way of communicating your ideas and exchanging thoughts. Moreover, it is also the best stage to decide to which publication you will submit the paper. Many people come up with three choices and discuss them with their mentors and colleagues. Having a list of journal priorities can help you quickly resubmit your paper if your paper is rejected.

### Rule 2: Create a detailed outline and discuss it with your mentor and peers.

## 3. Continue with drafts

After you get enough feedback and decide on the journal you will submit to, the process of real writing begins. Copy your outline into a separate file and expand on each of the points, adding data and elaborating on the details. When you create the first draft, do not succumb to the temptation of editing. Do not slow down to choose a better word or better phrase; do not halt to improve your sentence structure. Pour your ideas into the paper and leave revision and editing for later. As Paul Silvia explains, “Revising while you generate text is like drinking decaffeinated coffee in the early morning: noble idea, wrong time” [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R2)].

Many students complain that they are not productive writers because they experience writer’s block. Staring at an empty screen is frustrating, but your screen is not really empty: You have a template of your article, and all you need to do is fill in the blanks. Indeed, writer’s block is a logical fallacy for a scientist ― it is just an excuse to procrastinate. When scientists start writing a research paper, they already have their files with data, lab notes with materials and experimental designs, some visuals, and tables with results. All they need to do is scrutinize these pieces and put them together into a comprehensive paper.

## 3.1. Starting with Materials and Methods

If you still struggle with starting a paper, then write the Materials and Methods section first. Since you have all your notes, it should not be problematic for you to describe the experimental design and procedures. Your most important goal in this section is to be as explicit as possible by providing enough detail and references. In the end, the purpose of this section is to allow other researchers to evaluate and repeat your work. So do not run into the same problems as the writers of the sentences in (1):

1a. Bacteria were pelleted by centrifugation.

1b. To isolate T cells, lymph nodes were collected.

As you can see, crucial pieces of information are missing: the speed of centrifuging your bacteria, the time, and the temperature in (1a); the source of lymph nodes for collection in (b). The sentences can be improved when information is added, as in (2a) and (2b), respectfully:

2a. Bacteria were pelleted by centrifugation at 3000g for 15 min at 25°C.

2b. To isolate T cells, mediastinal and mesenteric lymph nodes from Balb/c mice were collected at day 7 after immunization with ovabumin.

If your method has previously been published and is well-known, then you should provide only the literature reference, as in (3a). If your method is unpublished, then you need to make sure you provide all essential details, as in (3b).

3a. Stem cells were isolated, according to Johnson [23].

3b. Stem cells were isolated using biotinylated carbon nanotubes coated with anti-CD34 antibodies.

Furthermore, cohesion and fluency are crucial in this section. One of the malpractices resulting in disrupted fluency is switching from passive voice to active and vice versa within the same paragraph, as shown in (4). This switching misleads and distracts the reader.

4. Behavioral computer-based experiments of Study 1 were programmed by using E-Prime. We took ratings of enjoyment, mood, and arousal as the patients listened to preferred pleasant music and unpreferred music by using Visual Analogue Scales (SI Methods). The preferred and unpreferred status of the music was operationalized along a continuum of pleasantness [[4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R4)].

The problem with (4) is that the reader has to switch from the point of view of the experiment (passive voice) to the point of view of the experimenter (active voice). This switch causes confusion about the performer of the actions in the first and the third sentences. To improve the coherence and fluency of the paragraph above, you should be consistent in choosing the point of view: first person “we” or passive voice [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R5)]. Let’s consider two revised examples in (5).

5a. We programmed behavioral computer-based experiments of Study 1 by using E-Prime. We took ratings of enjoyment, mood, and arousal by using Visual Analogue Scales (SI Methods) as the patients listened to preferred pleasant music and unpreferred music. We operationalized the preferred and unpreferred status of the music along a continuum of pleasantness.

5b. Behavioral computer-based experiments of Study 1 were programmed by using E-Prime. Ratings of enjoyment, mood, and arousal were taken as the patients listened to preferred pleasant music and unpreferred music by using Visual Analogue Scales (SI Methods). The preferred and unpreferred status of the music was operationalized along a continuum of pleasantness.

If you choose the point of view of the experimenter, then you may end up with repetitive “we did this” sentences. For many readers, paragraphs with sentences all beginning with “we” may also sound disruptive. So if you choose active sentences, you need to keep the number of “we” subjects to a minimum and vary the beginnings of the sentences [[6](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R6)].

Interestingly, recent studies have reported that the Materials and Methods section is the only section in research papers in which passive voice predominantly overrides the use of the active voice [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R5),[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R7),[8](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R8),[9](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R9)]. For example, Martínez shows a significant drop in active voice use in the Methods sections based on the corpus of 1 million words of experimental full text research articles in the biological sciences [[7](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R7)]. According to the author, the active voice patterned with “we” is used only as a tool to reveal personal responsibility for the procedural decisions in designing and performing experimental work. This means that while all other sections of the research paper use active voice, passive voice is still the most predominant in Materials and Methods sections.

Writing Materials and Methods sections is a meticulous and time consuming task requiring extreme accuracy and clarity. This is why when you complete your draft, you should ask for as much feedback from your colleagues as possible. Numerous readers of this section will help you identify the missing links and improve the technical style of this section.

### Rule 3: Be meticulous and accurate in describing the Materials and Methods. Do not change the point of view within one paragraph.

## 3.2. Writing Results Section

For many authors, writing the Results section is more intimidating than writing the Materials and Methods section . If people are interested in your paper, they are interested in your results. That is why it is vital to use all your writing skills to objectively present your key findings in an orderly and logical sequence using illustrative materials and text.

Your Results should be organized into different segments or subsections where each one presents the purpose of the experiment, your experimental approach, data including text and visuals (tables, figures, schematics, algorithms, and formulas), and data commentary. For most journals, your data commentary will include a meaningful summary of the data presented in the visuals and an explanation of the most significant findings. This data presentation should not repeat the data in the visuals, but rather highlight the most important points. In the “standard” research paper approach, your Results section should exclude data interpretation, leaving it for the Discussion section. However, interpretations gradually and secretly creep into research papers: “Reducing the data, generalizing from the data, and highlighting scientific cases are all highly interpretive processes. It should be clear by now that we do not let the data speak for themselves in research reports; in summarizing our results, we interpret them for the reader” [[10](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R10)]. As a result, many journals including the Journal of Experimental Medicine and the Journal of Clinical Investigation use joint Results/Discussion sections, where results are immediately followed by interpretations.

Another important aspect of this section is to create a comprehensive and supported argument or a well-researched case. This means that you should be selective in presenting data and choose only those experimental details that are essential for your reader to understand your findings. You might have conducted an experiment 20 times and collected numerous records, but this does not mean that you should present all those records in your paper. You need to distinguish your results from your data and be able to discard excessive experimental details that could distract and confuse the reader. However, creating a picture or an argument should not be confused with data manipulation or falsification, which is a willful distortion of data and results. If some of your findings contradict your ideas, you have to mention this and find a plausible explanation for the contradiction.

In addition, your text should not include irrelevant and peripheral information, including overview sentences, as in (6).

6. To show our results, we first introduce all components of experimental system and then describe the outcome of infections.

Indeed, wordiness convolutes your sentences and conceals your ideas from readers. One common source of wordiness is unnecessary intensifiers. Adverbial intensifiers such as “clearly,” “essential,” “quite,” “basically,” “rather,” “fairly,” “really,” and “virtually” not only add verbosity to your sentences, but also lower your results’ credibility. They appeal to the reader’s emotions but lower objectivity, as in the common examples in (7):

7a. Table 3 clearly shows that …

7b. It is obvious from figure 4 that …

Another source of wordiness is nominalizations, i.e., nouns derived from verbs and adjectives paired with weak verbs including “be,” “have,” “do,” “make,” “cause,” “provide,” and “get” and constructions such as “there is/are.”

8a. We tested the hypothesis that there is a disruption of membrane asymmetry.

8b. In this paper we provide an argument that stem cells repopulate injured organs.

In the sentences above, the abstract nominalizations “disruption” and “argument” do not contribute to the clarity of the sentences, but rather clutter them with useless vocabulary that distracts from the meaning. To improve your sentences, avoid unnecessary nominalizations and change passive verbs and constructions into active and direct sentences.

9a. We tested the hypothesis that the membrane asymmetry is disrupted.

9b. In this paper we argue that stem cells repopulate injured organs.

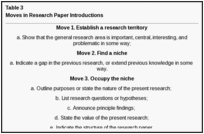
Your Results section is the heart of your paper, representing a year or more of your daily research. So lead your reader through your story by writing direct, concise, and clear sentences.

### Rule 4: Be clear, concise, and objective in describing your Results.

## 3.3. now it is time for your Introduction

Now that you are almost half through drafting your research paper, it is time to update your outline. While describing your Methods and Results, many of you diverged from the original outline and re-focused your ideas. So before you move on to create your Introduction, re-read your Methods and Results sections and change your outline to match your research focus. The updated outline will help you review the general picture of your paper, the topic, the main idea, and the purpose, which are all important for writing your introduction.

The best way to structure your introduction is to follow the three-move approach shown in [Table 3](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T3/).

[](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T3/)

**Moves in Research Paper Introductions**

The moves and information from your outline can help to create your Introduction efficiently and without missing steps. These moves are traffic signs that lead the reader through the road of your ideas. Each move plays an important role in your paper and should be presented with deep thought and care. When you establish the territory, you place your research in context and highlight the importance of your research topic. By finding the niche, you outline the scope of your research problem and enter the scientific dialogue. The final move, “occupying the niche,” is where you explain your research in a nutshell and highlight your paper’s significance. The three moves allow your readers to evaluate their interest in your paper and play a significant role in the paper review process, determining your paper reviewers.

Some academic writers assume that the reader “should follow the paper” to find the answers about your methodology and your findings. As a result, many novice writers do not present their experimental approach and the major findings, wrongly believing that the reader will locate the necessary information later while reading the subsequent sections [[5](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R5)]. However, this “suspense” approach is not appropriate for scientific writing. To interest the reader, scientific authors should be direct and straightforward and present informative one-sentence summaries of the results and the approach.

Another problem is that writers understate the significance of the Introduction. Many new researchers mistakenly think that all their readers understand the importance of the research question and omit this part. However, this assumption is faulty because the purpose of the section is not to evaluate the importance of the research question in general. The goal is to present the importance of your research contribution and your findings. Therefore, you should be explicit and clear in describing the benefit of the paper.

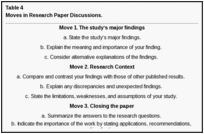
The Introduction should not be long. Indeed, for most journals, this is a very brief section of about 250 to 600 words, but it might be the most difficult section due to its importance.

### Rule 5: Interest your reader in the Introduction section by signalling all its elements and stating the novelty of the work.

## 3.4. Discussion of the results

For many scientists, writing a Discussion section is as scary as starting a paper. Most of the fear comes from the variation in the section. Since every paper has its unique results and findings, the Discussion section differs in its length, shape, and structure. However, some general principles of writing this section still exist. Knowing these rules, or “moves,” can change your attitude about this section and help you create a comprehensive interpretation of your results.

The purpose of the Discussion section is to place your findings in the research context and “to explain the meaning of the findings and why they are important, without appearing arrogant, condescending, or patronizing” [[11](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R11)]. The structure of the first two moves is almost a mirror reflection of the one in the Introduction. In the Introduction, you zoom in from general to specific and from the background to your research question; in the Discussion section, you zoom out from the summary of your findings to the research context, as shown in [Table 4](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T4/).

[](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T4/)

**Moves in Research Paper Discussions.**

The biggest challenge for many writers is the opening paragraph of the Discussion section. Following the moves in [Table 1](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/table/T1/), the best choice is to start with the study’s major findings that provide the answer to the research question in your Introduction. The most common starting phrases are “Our findings demonstrate . . .,” or “In this study, we have shown that . . .,” or “Our results suggest . . .” In some cases, however, reminding the reader about the research question or even providing a brief context and then stating the answer would make more sense. This is important in those cases where the researcher presents a number of findings or where more than one research question was presented. Your summary of the study’s major findings should be followed by your presentation of the importance of these findings. One of the most frequent mistakes of the novice writer is to assume the importance of his findings. Even if the importance is clear to you, it may not be obvious to your reader. Digesting the findings and their importance to your reader is as crucial as stating your research question.

Another useful strategy is to be proactive in the first move by predicting and commenting on the alternative explanations of the results. Addressing potential doubts will save you from painful comments about the wrong interpretation of your results and will present you as a thoughtful and considerate researcher. Moreover, the evaluation of the alternative explanations might help you create a logical step to the next move of the discussion section: the research context.

The goal of the research context move is to show how your findings fit into the general picture of the current research and how you contribute to the existing knowledge on the topic. This is also the place to discuss any discrepancies and unexpected findings that may otherwise distort the general picture of your paper. Moreover, outlining the scope of your research by showing the limitations, weaknesses, and assumptions is essential and adds modesty to your image as a scientist. However, make sure that you do not end your paper with the problems that override your findings. Try to suggest feasible explanations and solutions.

If your submission does not require a separate Conclusion section, then adding another paragraph about the “take-home message” is a must. This should be a general statement reiterating your answer to the research question and adding its scientific implications, practical application, or advice.

Just as in all other sections of your paper, the clear and precise language and concise comprehensive sentences are vital. However, in addition to that, your writing should convey confidence and authority. The easiest way to illustrate your tone is to use the active voice and the first person pronouns. Accompanied by clarity and succinctness, these tools are the best to convince your readers of your point and your ideas.

### Rule 6: Present the principles, relationships, and generalizations in a concise and convincing tone.

## 4. Choosing the best working revision strategies

Now that you have created the first draft, your attitude toward your writing should have improved. Moreover, you should feel more confident that you are able to accomplish your project and submit your paper within a reasonable timeframe. You also have worked out your writing schedule and followed it precisely. Do not stop ― you are only at the midpoint from your destination. Just as the best and most precious diamond is no more than an unattractive stone recognized only by trained professionals, your ideas and your results may go unnoticed if they are not polished and brushed. Despite your attempts to present your ideas in a logical and comprehensive way, first drafts are frequently a mess. Use the advice of Paul Silvia: “Your first drafts should sound like they were hastily translated from Icelandic by a non-native speaker” [[2](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R2)]. The degree of your success will depend on how you are able to revise and edit your paper.

The revision can be done at the macrostructure and the microstructure levels [[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R13)]. The macrostructure revision includes the revision of the organization, content, and flow. The microstructure level includes individual words, sentence structure, grammar, punctuation, and spelling.

The best way to approach the macrostructure revision is through the outline of the ideas in your paper. The last time you updated your outline was before writing the Introduction and the Discussion. Now that you have the beginning and the conclusion, you can take a bird’s-eye view of the whole paper. The outline will allow you to see if the ideas of your paper are coherently structured, if your results are logically built, and if the discussion is linked to the research question in the Introduction. You will be able to see if something is missing in any of the sections or if you need to rearrange your information to make your point.

The next step is to revise each of the sections starting from the beginning. Ideally, you should limit yourself to working on small sections of about five pages at a time [[14](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R14)]. After these short sections, your eyes get used to your writing and your efficiency in spotting problems decreases. When reading for content and organization, you should control your urge to edit your paper for sentence structure and grammar and focus only on the flow of your ideas and logic of your presentation. Experienced researchers tend to make almost three times the number of changes to meaning than novice writers [[15](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R15),[16](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/" \l "R16)]. Revising is a difficult but useful skill, which academic writers obtain with years of practice.

In contrast to the macrostructure revision, which is a linear process and is done usually through a detailed outline and by sections, microstructure revision is a non-linear process. While the goal of the macrostructure revision is to analyze your ideas and their logic, the goal of the microstructure editing is to scrutinize the form of your ideas: your paragraphs, sentences, and words. You do not need and are not recommended to follow the order of the paper to perform this type of revision. You can start from the end or from different sections. You can even revise by reading sentences backward, sentence by sentence and word by word.

One of the microstructure revision strategies frequently used during writing center consultations is to read the paper aloud [[17](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R17)]. You may read aloud to yourself, to a tape recorder, or to a colleague or friend. When reading and listening to your paper, you are more likely to notice the places where the fluency is disrupted and where you stumble because of a very long and unclear sentence or a wrong connector.

Another revision strategy is to learn your common errors and to do a targeted search for them [[13](https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3178846/#R13)]. All writers have a set of problems that are specific to them, i.e., their writing idiosyncrasies. Remembering these problems is as important for an academic writer as remembering your friends’ birthdays. Create a list of these idiosyncrasies and run a search for these problems using your word processor. If your problem is demonstrative pronouns without summary words, then search for “this/these/those” in your text and check if you used the word appropriately. If you have a problem with intensifiers, then search for “really” or “very” and delete them from the text. The same targeted search can be done to eliminate wordiness. Searching for “there is/are” or “and” can help you avoid the bulky sentences.

The final strategy is working with a hard copy and a pencil. Print a double space copy with font size 14 and re-read your paper in several steps. Try reading your paper line by line with the rest of the text covered with a piece of paper. When you are forced to see only a small portion of your writing, you are less likely to get distracted and are more likely to notice problems. You will end up spotting more unnecessary words, wrongly worded phrases, or unparallel constructions.

After you apply all these strategies, you are ready to share your writing with your friends, colleagues, and a writing advisor in the writing center. Get as much feedback as you can, especially from non-specialists in your field. Patiently listen to what others say to you ― you are not expected to defend your writing or explain what you wanted to say. You may decide what you want to change and how after you receive the feedback and sort it in your head. Even though some researchers make the revision an endless process and can hardly stop after a 14th draft; having from five to seven drafts of your paper is a norm in the sciences. If you can’t stop revising, then set a deadline for yourself and stick to it. Deadlines always help.

### Rule 7: Revise your paper at the macrostructure and the microstructure level using different strategies and techniques. Receive feedback and revise again.

## 5. It is time to submit

It is late at night again. You are still in your lab finishing revisions and getting ready to submit your paper. You feel happy ― you have finally finished a year’s worth of work. You will submit your paper tomorrow, and regardless of the outcome, you know that you can do it. If one journal does not take your paper, you will take advantage of the feedback and resubmit again. You will have a publication, and this is the most important achievement.

What is even more important is that you have your scheduled writing time that you are going to keep for your future publications, for reading and taking notes, for writing grants, and for reviewing papers. You are not going to lose stamina this time, and you will become a productive scientist. But for now, let’s celebrate the end of the paper.

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ABSTRACTS:

A. Excerpted from: Hasegawa, K., Sakoda, M. and J. Bruinsma. 1989. Revision of the theory of phototropism in plants: a new interpretation of a classical experiment. Planta 178:540-544.

Went's classical experiment on the diffusion of auxin activity from unilaterally illuminated oat coleoptile tips (Went 1928), was repeated as precisely as possible. In agreement with Went's data with the *Avena* curvature assay, the agar blocks from the illuminated side of oat (*Avena* *sativa* L. cv. Victory) coleoptile tips had, on the average, 38% of the auxin activity of those from the shaded side. However, determination of the absolute amounts of indole-3-acetic acid (IAA) in the agar blocks, using a physicochemical assay following purification, showed that the IAA was evenly distributed in the blocks from the illuminated and shaded sides. In the blocks from the shaded and dark-control halves the amounts of IAA were 2.5 times higher than the auxin activity measured by the *Avena* curvature test, and in those from the illuminated half even 7 times higher. Chromatography of the diffusates prior to the *Avena* curvature test demonstrated that the amounts of two growth inhibitors, especially of the more polar one, were significantly higher in the agar blocks from the illuminated side than in those from the shaded side and the dark control. These results show that the basic experiment from which the Cholodny-Went theory was derived does not justify this theory. The data rather indicate that phototropism is caused by the light-induced, local accumulation of growth inhibitors against a background of even auxin distribution, the diffusion of auxin being unaffected.

B. Excerpted from: Farmer, E.E. and Ryan, C.A. 1990. Interplant communication: airborne methyl jasmonate induces synthesis of proteinase inhibitors in plant leaves. Proc. Natl. Acad. Sci. 87: 7713-7716.

Inducible defensive responses in plants are known to be activated locally and systematically by signaling molecules that are produced at sites of pathogen or insect attacks, but only one chemical signal, ethylene, is known to travel through the atmosphere to activate plant defensive genes. Methyl jasmonate, a common plant secondary compound, when applied to surfaces of tomato plants, induces the synthesis of defensive proteinase inhibitor proteins in the treated plants and in nearby plants as well. The presence of methyl jasmonate in the atmosphere of chambers containing plants from three species of two families, Solanaceae and Fabaceae, results in the accumulation of proteinase inhibitors in leaves of all three species. When sagebrush, *Artemesia* *tridentata*, a plant shown to possess methyl jasmonate in leaf surface structures, is incubated in chambers with tomato plants, proteinase inhibitor accumulation is induced in the tomato leaves, demonstrating that interplant communication can occur from leaves of one species of plant to leaves of another species to activate the expression of defensive genes.

INTRODUCTIONS:

A. Excerpted from: Shukla, A. and Sawhney, V.K. 1992. Cytokinins in a genic male sterile line of *Brassica* *napus*. Physiol. Plant. 85:23-29.

The failure or inability of an individual to produce functional gametes under a given set of environmental conditions is known as sterility. Male sterility in plants is generally associated with the lack of production of viable pollen; however its expression can vary (Frankel and Galun 1977, Kaul 1988). In any event, male sterility is of fundamental importance in the production of hybrid seeds and in breeding programs.

Plant growth substances, both exogenously applied and endogenous, have often been implicated in the regulation of male sterility in several plant species (Frankel and Galun 1977, Kaul 1988). Cytokinins, gibberellins, auxins and abscisic acid, as well as polyamines, are all known to affect pollen and stamen development in a number of species (e.g., Sawhney 1974, Ahokas 1982, Saini and Aspinall 1982, Rastogi and Sawhney 1990, Nakajima *et al.* 1991, Singh *et al.* 1992).

[Several paragraphs with more background material were omitted]

The objective of this study was to determine a possible relationship between endogenous cytokinins with male sterility in the genic male sterile system in *Brassica* *napus*. Thus, an analysis of a number of cytokinins in various organs of the wild type and genic male sterile plants was conducted.

B. Excerpted from: Reader, R.J. and Beisner, B.E. 1991. Species-dependent effects of seed predation and ground cover on seedling emergence of old-field forbs. Am. Midl. Nat. 126: 279-286.

A major goal of plant ecology is to explain spatial variation in a species frequency of occurrence. Spatial variation in seed predation may contribute to spatial variation in plant frequency by reducing seed supply sufficiently to limit seedling emergence more at one location than another (Louda 1982, Anderson 1989). Spatial variation in seed predation is well documented (*e.g*., Janzen 1971, 1975,; Bertness *et al.* 1987; Smith 1987), but few investigators tested whether differential seed predation resulted in differential seedling emergence (*e.g*., Louda 1982, 1983). Since factors such as dense ground cover may suppress seedling emergence regardless of the amount of seed predation (Harper 1977), additional studies are needed to clarify the effect of seed predation on seedling emergence. Therefore, we examined the effects of both seed predation and ground cover (*i.e*., plant biomass and litter) on seedling emergence of some old-field forbs.

MATERIALS AND METHODS:

A. Extracted from: Sakoda, M., Hasegawa, K. and Ishizuka, K. 1992. Mode of action of natural growth inhibitors in radish hypocotyl elongation -- influence of raphanusanins on auxin-mediated microtubule orientation. Physiol. Plant. 84:509-513.

Seeds of *Raphanus* *sativus* L. var. *hortensis* f. *shogoin* were sown and germinated in petri dishes on 4 layers of paper-towel (Kimberly-Clark Corp.) moistened with distilled water. After 3 days in darkness at 25oC, 4-mm hypocotyl segments were excised below the hook of the 3 cm long etiolated seedlings. After subapical segments were held for 1 h in darkness at 25oC in distilled water, they were transferred to 1 mM IAA solution or mixed media containing 1 mM IAA and raphanusanin B ( 1 or 3 mM). In other experiments, segments were preincubated for 1 h in small petri dishes containing 1 mM IAA solution, and then raphanusanin B was added to the medium (final concentrations 1 or 3 mM). Segment lengths were measured using a microscope with microgauge. All manipulations were carried out under dim green light (3mW m-2).

[The authors then explained visualization of microtubules by immunofluorescence]

B. Excerpted from: Kanbe, T., Kobayashi, I and Tanaka, K. !992. Dynamics of cytoplasmic organelles in the cell cycle of the fission yeast *Schizosaccharomyces* *pombe*: Three-dimensional reconstruction from serial sections. J. Cell Sci.,94: 647-656.

*Schizosaccharomyces* *pombe* h90, the homothallic, readily sporing haploid strain, was used. The strain was maintained on malt extract-yeast extract (MY) agar as described by Tanaka and Kanbe (1986). Cells were cultured on a MY slant at 30oC for 48 h, transferred to MY broth and cultures at 30oC overnight. Cells at the exponential phase were spread on a MY plate and further incubated at 30oC for 4 to 6 h before harvesting for microscopy.

Cells were fixed with a solution of 3% paraformaldehyde in a 50mM-phosphate buffer containing 1mM-MgCl2 (pH 6.8) at room temperature for 2 h. After washing with the buffer, cells were treated with Novozyme 234 (Novo Industri A/S, Bagsvaerd, Denmark) for 60 min at 30oC with reciprocal shaking to remove the cell wall. For the staining of F-actin, cells were washed and suspended in Rh-ph solution (Molecular Probes, Inc., Eugene, OR, USA) diluted 20 times in 50 mM-phosphate-buffered saline containing 1mM-MgCl2 (PBS, pH 7.3) at room temperature for 2 h. Nuclei were stained by 4,6-diamidino-2-phenylindole (DAPI) in NS buffer described by Suzuki *et* *al*. (1982). Preparations were examined with an Olympus BHS-RFK epifluorescence microscope using a U-G dichroic mirror with excitation filter BP490 for Rh-ph staining and UG1 for DAPI, and were photographed on Kodak Tmax400 film.

[This section continued to describe preparation for electron microscopy and the three-dimensional reconstruction of serial sections.]

RESULTS:

A. Excerpted from: Takahashi, H., Scott, T.K. and Suge, H. 1992. Stimulation of root elongation and curvature by calcium. Plant Physiol. 98:246-252.

As shown in Table 1, the growth of roots treated with 10 mM Ca2+ was approximately 30% greater than the controls for a 3.5 h period following Ca2+ application to Alaska pea roots and approximately 80% greater than control for 12 h following the treatment in *ageotropum* pea. However, the growth of Alaska pea roots did not differ from that of control roots when measured 12 h after Ca2+ treatment. Roots of Silver Queen corn also showed an increase of approximately 70% in growth 3 h following application of 20 mM Ca2+ (Table 1). Such symmetrical treatment of root caps with Ca2+ did not cause curvature of the roots.

[The results section continued for several more paragraphs.]

B. Excerpted from: Sato, S. and Dickinson, H.G. 1991. The RNA content of the nucleolus and nucleolus-like inclusions in the anther of Lilium estimated by an improved RNase-gold labelling method. Jour. Cell Sci. 94:675-683.

Gold particles were predominant over the nuclear nucleolus-like bodies (NLBs) (Fig. 9). Although the distribution histogram of gold particles over the nuclear NLBs showed that labelling varied from 40 to 130 particles mm-2, most of that fell in the range of 80 - 90 particles mm-2 (Fig. 4). The quantitative estimation of labelling, which represented the average number of gold particles per mm2, indicated the labelling over the nuclear NLBs to be twice as strong as that over the loosened chromatin, and four times as strong as that over the condensed chromatin (Table 2).

[The results section continued for several more paragraphs.]

DISCUSSION:

A. Excerpted from: Takahashi, H., Scott, T.K. and Suge, H. 1992. Stimulation of root elongation and curvature by calcium. Plant Physiol. 98:246-252.

The effect of Ca2+ on root elongation has been reported to be both stimulatory and inhibitory (Burstrom 1969, Evans *et al*. 1990, Hasenstein and Evans 1986). In those initial studies , however, the whole root was treated with Ca2+. Because the site of action for Ca2+ in gravitropism is considered to be the root cap rather than the zone of elongation, we focused on the role of the Ca2+/cap interaction in root growth as well as in gravitropic responses. We found that Ca2+ at 10 or 20 mM applied to the cap end of pea and corn roots mediated elongation growth of roots for at least 3 to 4 h following treatment. Unilateral application of 1 to 20 mM Ca2+ to the root cap always induced unequivocal curvature of roots away from the Ca2+ source in Alaska pea and to a greater extent in the roots of the agravitropic mutant, *ageotropum* (Figs. 1 and 2). Roots of Merit and Silver Queen corn also always curved away from Ca2+ applied to the cap, although a somewhat higher concentration was required for the response than in the pea roots. [Several sentences were omitted here.] These results show a strong correlation between an increase of Ca2+ levels in the root cap and stimulation of root elongation. The results are in contrast to the previously proposed model that an increased level of Ca2+ in the root cap mediated inhibition of root growth (Hasenstein et al. 1988).

[The discussion continued for several more paragraphs.]

CONCLUSIONS:

A. Excerpted from: Noguchi, H. and Hasegawa, K. 1987. Phototropism in hypocotyls of radish. III. Influence of unilateral or bilateral illumination of various light intensities on phototropism and distribution of *cis*- and *trans*-raphanusanins and raphanusamide. Plant Physiol. 83: 672-675.

The present study demonstrates that phototropism in radish hypocotyls is caused by a gradient of growth inhibition which depends on the light intensity through the amounts of growth inhibitor, and thus strongly supports the Blaauw (Blaauw 1915) hypothesis, explaining phototropism as an effect of local growth inhibition by light.

B. Excerpted from: Nick, P., Bergfeld, R., Schäfer, E. and Schopfer, P. 1990. Unilateral reorientation of microtubules at the outer epidermal wall during photo- and gravitropic curvature of maize coleoptiles and sunflower hypocotyls. Planta 181: 162-168.

The striking agreement between changes in microtubule orientation observed at the outer epidermal wall during tropic bending and during induction or straight growth by external auxin strongly indicates that auxin is, in fact, functionally involved in mediating asymmetric growth leading to organ curvature.

There is no evidence that short-term growth of epidermal cells is controlled through the orientation of microfibrils. Also the data do not prove a causal relationship between auxin action on microtubule orientation and tropic curvature. However, our results do show that microtubule reorientation is a specific auxin-mediated response which can be used as a diagnostic test for an asymmetric distribution of the hormone, correlated with asymmetric growth.