

A GUIDE TO WRITING SCIENTIFIC PAPERS

(Reviewed Fall 2009)

Good communication is essential to scientific research. Investigators communicate the results of their work in the form of *scientific papers* that are typically published in *journals* (i.e., periodicals) that are specific to a particular field of study. Such papers are commonly referred to as *primary literature*.

Although each journal has its own specific guidelines for paper format, the basic foundation of all scientific papers is similar. In general, a paper must describe:

- A question or problem to be investigated.
- A protocol or experiment used to investigate the problem.
- Data and observations gathered from the experiment.
- An answer to the question (i.e., a conclusion) based on the observations.

These critical areas are usually addressed in different sections of the paper. In addition to an appropriate *title*, a typical paper will include the following sections, each clearly identified with its own section heading: *Abstract*; *Introduction*; *Materials and Methods*; *Results*; *Discussion*; *Acknowledgements*; and *Literature Cited*.

TITLE

Every scientific paper must have a self-explanatory title. In general, the title should convey the following information:

1. The variable (environmental factor) that was manipulated.
2. The parameter that was measured.
3. The specific organism or biological system that was studied.

For example, "The effect of light intensity on the growth of *Escherichia coli*" would be an appropriate title. In contrast, titles such as "The effect of light on bacteria" or "A biology lab report" would fail to convey all the necessary information.

ABSTRACT

The abstract section in a scientific paper is a concise, self-explanatory *digest* of the content of the paper. The abstract should present, in about 250 words, the purpose of the paper, basic protocol, summarized results, and the major conclusions. Detailed background information, analysis, and descriptions are excluded, as are tables, figures and (typically) citations.

WRITER'S TIP: Write your abstract last. A useful approach is to summarize the most important points from each section of the paper in a few concise sentences and then assemble those sentences to construct a brief description of your study.

INTRODUCTION

The Introduction serves two key purposes. First, it provides some relevant background information to place your study into a larger biological context. Second, it provides a clear statement of the question or problem being investigated.

The background should give readers enough information to appreciate your specific objectives within a larger theoretical framework. This will often include a summary of previous research that has been done on this problem, and will indicate how the present experiment will help to clarify or expand the knowledge in this general area. All background information gathered from other sources must be appropriately cited. (The proper formatting of citations in the text of the paper is detailed in Appendix A.)

As with the title, your statement of purpose should be sufficiently detailed. Be sure to indicate the specific variable(s) being manipulated, the parameter(s) being measured, and the specific organism(s) or biological system(s) studied.

The introduction would also be the appropriate place to present your *hypothesis*. A hypothesis represents an expected outcome, based on prior research. A hypothesis is more than just a guess--it must be scientifically valid, and the reasoning behind it must be clear from the background information you have provided.

WRITER'S TIP: An introduction usually progresses from a *general* theoretical framework to a *specific* question. However, do not make the Introduction *too* broad--keep in mind that your target audience should have a level of knowledge similar to yours. Present only the most relevant ideas and get quickly to the point of the paper.

MATERIALS AND METHODS

Materials and Methods provides a description of the protocol employed in the investigation, including the experimental design, apparatus used, methods of gathering data, and type of control. If any work was done in a natural habitat, a detailed description of the study area should be provided. If specimens were collected for study, where and when that material was collected is stated. In brief, sufficient information should be provided so that a reader could duplicate your study if they choose to do so.

Because your target audience is a group of researchers with similar knowledge and skills as you, it is NOT necessary to detail "standard procedures" such as using a microscope or loading an agarose gel. Also, complex procedures that are documented elsewhere are sometimes described simply by citing the original source. (e.g., "Respirometers were assembled as described in Colby (2007).")

WRITER'S TIP: Materials and Methods is a PAST TENSE NARRATIVE of your experimental procedure--DO NOT write it as though it were a set of directions in a laboratory handout, DO NOT include LISTS of equipment or supplies. The following examples illustrate the wrong and right way to approach this section.

WRONG: "First pour agar into six petri plates. Then inoculate the plates with the bacteria. Then put the plates into the incubator. Wait ten hours."

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

RESULTS

Results provides an objective presentation of the information gathered in the investigation. Here, data collected in the experiment are *summarized* and *organized* into a meaningful form that can be used to address the experimental question posed in the Introduction. Although this seems like a simple task, crafting an effective Results section can be quite challenging.

For many types of data, *figures* and *tables* are used to visually organize information. The importance of creating good figures and tables cannot be overstated--their construction and use is covered in detail in Appendix B.

DO NOT present raw data! Use *descriptive statistics* (such as mean and standard error) to describe the central tendency and variability of groups. The importance of using appropriate descriptive statistics cannot be overstated--commonly used examples are covered in the separate handout "Working with Statistics."

Figures and tables must NEVER be left to stand alone. The Results section always includes NARRATIVE TEXT that *references each figure or table by number* and *summarizes the important information* presented in each. Keep in mind that the text should help focus the reader on the key points of the results--therefore, avoid simply repeating the information already presented in the figures and tables. The text of the Results is also the place to present the results of any *comparative statistical tests* that you may have employed. A detailed discussion on the use and presentation of comparative statistics can be found in the separate handout "Working with Statistics."

Lastly, keep in mind that Results is NOT the place to interpret or draw conclusions from your data. These will be developed in the next section of the paper.

WRITER'S TIP: Before you begin to draft your Results, answer the following questions:

What is the important message that I want my reader to see?

Answering this question requires that you have a firm grasp of the problem you are investigating, since your results will ultimately be used to support your conclusion (i.e., the answer to your experimental question).

How do I best convey that information?

Answering this second question largely depends on the type of data you are presenting--a figure (i.e., graph, chart, or picture) is often a great choice, but not all data is appropriate for this type of presentation. Sometimes a table or even just text is a better choice.

DISCUSSION

The Discussion section provides an interpretation of the information gathered in the investigation. This may include descriptions of important patterns, relationships, and correlations observed among variables. It may also include valid but speculative biological explanations of *why* certain results were observed.

The Discussion serves two major purposes. First, it's where you offer your *conclusion*. The conclusion is an answer to your experimental question, *based on your results*. This is an important point and it bears repeating--*your conclusion must be supported by the empirical evidence gathered during your experiment and presented in Results*.

(NOTE: Some papers will place the conclusion in a separate section. In such cases, detailed analysis, speculative explanations, and contextual information are reserved for the Discussion.)

It is less important that you reach a particular conclusion (i.e., "get the right answer") or that your conclusion "fits" your hypothesis. Often this will not be the case! When this happens, you should speculate on its meaning. Do you need to revise your hypothesis, your methodology, or both? 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.

Second, the discussion should place your findings into the broader biological context. Why is what you have learned important? What are the implications for further research? What questions remain unanswered?

WRITER'S TIP: 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 progressed from general background to a specific question, structuring the discussion to progress from your specific conclusions back to a broader general context will help to tie your ideas and arguments together.

ACKNOWLEDGEMENTS

In the Acknowledgements you give credit to people who have helped you with the research or with writing the paper. (In introductory biology this will typically include your lab partners or the other students in your lab section.) 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 proper formatting of citations both in the text of the paper and in the Literature Cited section is detailed in Appendix A.

A Few Tips on Style and Organization

As you have learned scientific papers follow strict formatting rules. Effective scientific writing, however, depends not only on the format and content of your paper, but also on the overall clarity and organization of your presentation. Good writing, regardless of the topic, is a skill that must be practiced and developed over time. Here are a few tips to help focus your efforts:

Tense

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 and Discussion 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.

Voice

Scientific papers are often written in the *passive voice*; e.g., "Six petri plates were prepared." Some authors use the *active voice*; e.g., "We prepared six petri plates." Whichever approach you choose, be consistent throughout the paper.

Usage

Language is fraught with grammatical challenges--using words properly is the hallmark of a good writer. The separate handout "Biology Writer's Usage Manual" provides several tips that will help polish your grammatical skills.

Clarity and Organization

Beginning writers often build papers by writing sentences that are then strung together into (sometimes long) paragraphs. This "bottom up" approach to writing usually results in a paper that is a series of disjointed points. A better strategy is to utilize a "top down" approach in which you *first* organize your major points in a logical fashion. Each point is then developed into a series of paragraphs, and each paragraph is developed into a series of sentences. You can facilitate this process by beginning each paper with a thorough outline!

Spelling and Punctuation

This should be self-evident. Nothing detracts from an otherwise good paper more than sloppy proofreading!

Additional Resources

For your reference, Appendix C offers some examples of excerpts from the scientific literature.

To assist you in evaluating your own papers, Appendix D provides a concise checklist of the key points covered in this guide.

Colby's Farnham Writer's Center (www.colby.edu/writers.center), located in Miller Library, offers help and tutoring on a variety of writing assignments

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 A: USE OF CITATIONS IN SCIENTIFIC WRITING

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 a laboratory handout.

Schneider MJ, Troxler RF, Voth PD. 1967. Occurrence of indoleacetic acid in the bryophytes. *Bot. Gaz.* 28(3):174-179.

Stebbins GL. 1977. *Processes of Organic Evolution*. Englewood Cliffs, NJ: Prentice-Hall. 269 p.

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.

Also, please note that many journal articles are now available online. Regardless of the format (paper or electronic), these are still considered journal articles and should be cited as such. DO NOT cite electronic journal articles as though they were Web sites!

APPENDIX B: THE CONSTRUCTION AND USE OF TABLES AND FIGURES

1. Summarized data presented in columns and rows are referred to as **tables**. All other items (graphs, pictures, drawings, maps, etc.) are referred to as **figures**. **Do not** refer to figures as "graphs" or "charts."
2. Tables often are used to present many numerical values. For example:

Table 1. Mineral element composition of several plant species grown in the same soil.

Species	Mineral Element Content (Percent Dry Weight)				
	Ca	K	Mg	N	P
Sunflower	1.7	3.5	0.7	1.5	0.08
Bean	1.5	1.2	0.6	1.5	0.05
Wheat	0.5	4.2	0.2	2.3	0.06
Barley	0.7	4.0	0.3	1.9	0.13

3. When you need to show a pattern or a trend in the data, you should consider using a graph. When the independent (treatment) values share a common unit, a scatter (or line) graph might be appropriate:

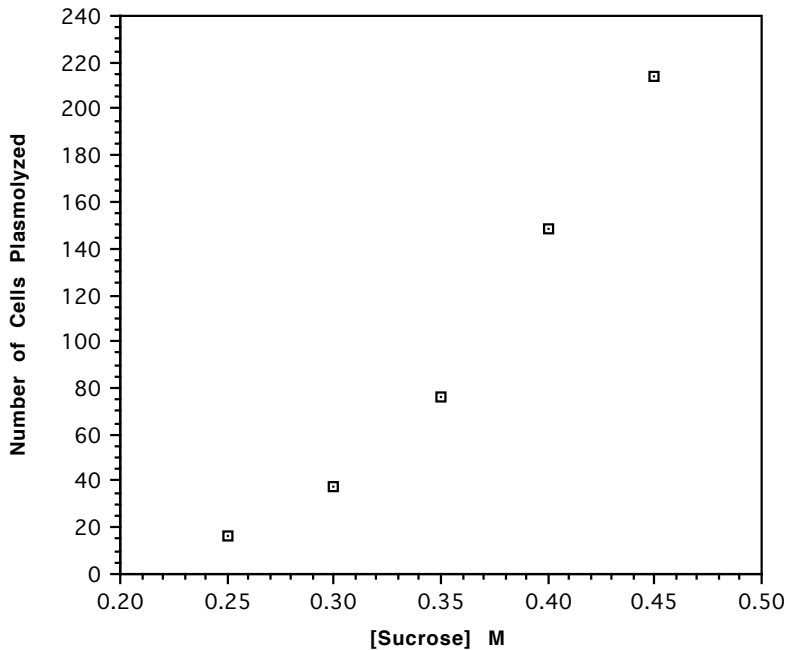


Figure 1. Plasmolysis of *Allium* bulb outer epidermal cells in external sucrose solutions at various concentrations. Number of cells observed = 230 / treatment.

At other times (when treatments are not related, for example), a bar graph is better:

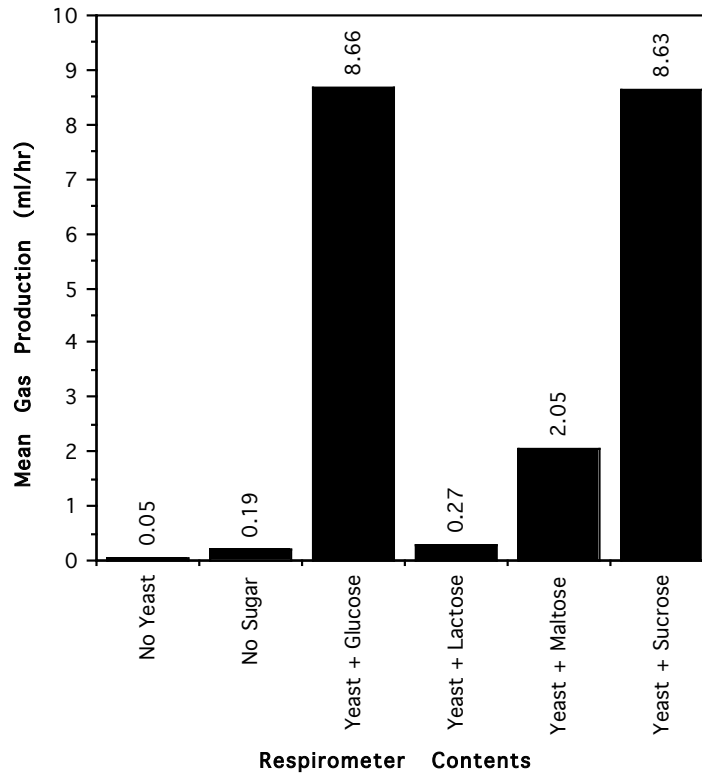


Figure 1. Gas production by yeast respiration in media supplemented with various sugars.

4. All tables and figures must include the *units* of measurement involved. All columns in a table should have separate headings identifying the entries. On both axes of graphs, name the variable and its corresponding unit of measurement. The independent variable is placed on the x-axis and the dependent variable is placed on the y-axis.
5. All tables and figures must be numbered. Tables and figures are numbered independently of each other. For example, with three tables and two figures, the tables would be labeled Table 1, Table 2, Table 3 and the figures would be labeled Figure 1 and Figure 2. Tables and figures are assigned their respective numbers by the order in which they are first mentioned in the text.
6. All tables and figures must have self-explanatory titles. The "rules" for composing the titles are the same as those for composing the title of a paper itself. The reader should be able to look at a table or figure and, simply by reading its title, know exactly what was done in that part of the experiment without having to read the text of the paper for information. Titles and labels for tables are always placed at the top of the table. Titles and labels for figures are always placed below the figure.
7. Whenever a table or figure is included in the paper, some reference to that table or figure must be included in the text of the paper. For example, "The effect of various concentrations of gibberellic acid on the growth in height of tomato plants is summarized in Table 1." or "Various concentrations of gibberellic acid have different effects on growth in height of tomato plants (Table 1)."

APPENDIX C: SELECTED EXAMPLES FROM THE SCIENTIFIC LITERATURE

ABSTRACTS:

- A. Excerpted from: Hasegawa K, Sakoda M, Bruinsma J. 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 EE, Ryan CA. 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, *Artemisia 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, Sawhney VK. 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 RJ, Beisner BE. 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, 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 25°C, 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 25°C in distilled water, they were transferred to 1 μM IAA solution or mixed media containing 1 μM IAA and raphanusanin B (1 or 3 mM). In other experiments, segments were preincubated for 1 h in small petri dishes containing 1 μM 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, Tanaka K. 1992. 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 30°C for 48 h, transferred to MY broth and cultures at 30°C overnight. Cells at the exponential phase were spread on a MY plate and further incubated at 30°C 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 30°C 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 TK, 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, Dickinson HG. 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 μm^{-2} , most of that fell in the range of 80 - 90 particles μm^{-2} (Fig. 4). The quantitative estimation of labelling, which represented the average number of gold particles per μm^2 , 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 TK, 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, 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, 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.

APPENDIX D: SELF-EVALUATION CHECKLIST FOR BIOLOGY PAPERS

(Specific papers may not contain all the sections included here.)

GENERAL

- Is the paper aimed at an audience of students having backgrounds and experiences similar to yours? Could such readers understand what you have written? Have you avoided trying to aim the paper at your instructors?
- Is the paper free of errors in spelling, punctuation, and grammar?

TITLE

- Does the title reflect the work presented in the paper? Does it include the **specific** details relevant to your study?

ABSTRACT

- Can the abstract stand by itself, telling the reader the question you investigated, the methods you used, your results, and your conclusions?
- Have you condensed the abstract to include **only** the most important points from each section of the paper? Is excessive detail avoided?

INTRODUCTION

- Have you provided some background information that places your work in a broader biological context?
- Is the introduction focused? Have you avoided tangential information that may have only limited relevance to your study?
- Have you clearly stated the **specific** problem that you investigated?
- Have you stated a hypothesis? Is the reasoning behind your hypothesis biologically valid? Is that reasoning clear to the reader?

MATERIALS AND METHODS

- Have you provided enough detail so that another student, using only your paper and the lab handout, could repeat your experiment?
- If you have referenced procedures described in detail elsewhere (i.e., lab handouts, other papers), have you cited those sources appropriately?

RESULTS

- Have you **summarized** the outcome of your experiment using descriptive statistics (e.g. mean, range, etc.) where appropriate? Have you avoided including raw data?
- Where appropriate, have you presented summarized results in figures and/or tables? Are figures and tables presented in the proper professional format?
- Have you included results in a table that could be presented more clearly in a figure (and vice-versa)? If you have used a figure, have you chosen the best kind of figure (i.e. scatter plot, bar graph, pie chart, etc.) to present your particular results? **YOU MUST DECIDE WHAT YOU WANT THE READER TO SEE IN YOUR RESULTS--CHOOSE YOUR PRESENTATION APPROPRIATELY!**
- Have you included narrative text? Are all figures and/or tables appropriately referenced in the text?
- Does the text point out important features or trends in the data which you want your readers to notice? Have you avoided simply repeating data that is already presented elsewhere in figures and/or tables?
- Have you avoided interpretations, judgments, or conclusions which belong in other sections of the paper?

DISCUSSION

- Have you answered the problem you presented in the introduction?
- Are your conclusions supported by the results of your experiment? Is the connection between the results and the conclusions clear?
- Have you provided reasonable explanations for atypical or unexpected results?
- Have you related your results back to the broader biological concepts presented in the introduction?

ACKNOWLEDGMENTS

- Have you acknowledged the help of others (e.g., lab partners), giving their names and describing their exact contributions?

LITERATURE CITED

- Are these complete and in a standard format?