14 Review Paper in the Natural Sciences

The scientific review paper consists of a clear and understandable explanation of the state of knowledge in a limited scientific area. The best review papers summarize the present situation in an ongoing field of research. Your review paper should bring your readers up to date, saving them the effort of locating, reading, and comparing original research publications. Your paper should also present the information at an appropriate level of technicality so that your readers can understand it, even though they might have trouble understanding the original research publications.

Because the purpose of the scientific review paper is to inform an already interested reader as efficiently as possible, the paper has a characteristic "scientific writing" style which emphasizes conspicuous organization, clarity, and brevity.

Some strategies that you can use effectively for term papers in the humanities are inappropriate for the scientific review paper. Remember that your contribution in writing a scientific review is in the organization, explanation, and clear presentation of complex concepts. Additional personal commentary on your topic frequently backfires by undermining your reader's confidence in your explanations. For example, you should not take a position on your topic; that is, you should not argue that one group of researchers is right and another group is wrong. Your paper is not designed to be argumentative (chapter 4), especially since any discrepancies will eventually be resolved by additional research. Also, you are not expected to come up with a new or original way of looking at the material. Only a scientist with many years of experience even attempts to do that.

In writing this type of term paper it is your responsibility to:

1 Select a topic that is appropriate to the course and suitably limited in scope. The best topics deal with problems under active investigation, rather than with problems that have been solved.

2 Identify and read the recent literature on the topic. The amount of literature may compel you either to expand or (more likely) reduce the scope of your topic to produce a paper of the desired length.

3 Organize the information into a meaningful pattern, using subheadings and sometimes an outline.

4 Paraphrase and simplify the information in the original articles and integrate it into the structure of your paper. (See chapter 5.)

5 Complete the paper using a format and writing style that are appropriate for a scientific review paper.

Getting started

Discovering a workable topic is the single most important determinant of the success of your review. Even before you begin to speculate on potential topics, look through your science textbook to ascertain the scope of acceptable topics. If you already have a topic on which you want to work, make certain that it falls within the subject matter covered in the course. Some topics are not wise choices even if they fall within the scope of the course. Sometimes a topic that has stimulated your interest because of its coverage by the popular media will present hidden difficulties when you try to use it as a topic for a scientific review. For example, the topic may be too complex: a paper on the development of a better flashlight battery becomes a chemical nightmare as you try to describe topochemical reactions of lithium and transition metal compounds. Or the topic may be too diffuse: a paper on the cause of infant crib death becomes a listing of the twenty or so most likely causes for this vaguely defined syndrome. Or finally, the topic could be too speculative: a paper on the use of pickled bats' feet as a cure for cancer becomes a futile search for recent journal articles because no reputable research has been done on the problem. Also, your library facilities may limit your topic. For example, unless you have access to a medical school library, you will find it difficult to obtain information on medical topics.

While you should be genuinely curious about your topic, be sure that your curiosity concerns the scientific features of the subject, not the emotional. In a course in the philosophy of science, in the history of science, or in freshman composition, you can find opportunities to write about the ethical and historical implications of popular topics, but for hard-core science courses, focus on the current state of scientific knowledge in the area defined by your research questions. If you have any doubts about your topic choice, check with your professor before investing time in library research.

As you begin to select a topic, consider using one of these three strategies, all designed to produce a rewarding and impressive review paper:

1 Look carefully at recent research reports, select one, and use it as a basis for your library search.

2 Look at the bibliography in your textbook, select a reference, and use it as a basis for your library search.

3 Look for a professionally written scientific review, select part of it as your paper topic, and then do a library search for up-to-date information.

Looking at recent research reports

By going to the recent issues of respected scientific journals, you will be able to identify a topic that the experts consider an exciting area of ongoing research. Writing on such a topic will let you share in the excitement of scientific research in progress.

This strategy has the distinct benefit of simplifying your library search. If you use a recently published journal, then you will have the most up-to-date information, complete with a list of appropriate references. On the other hand, the drawback to this method is the difficulty of understanding the writing in specialized scientific journals. To overcome the complexity of scientific research reports, you should select research journals appropriate to your level. If you are writing a relatively short paper assigned in a freshman-sophomore course, you might consult scientific journals aimed at the educated public. Such journals include *Scientific American*, *American Scientist*, *Bioscience*, *National Geographic*, *Smithsonian*, *Natural History*, and *Science 80*. Even the weekly magazine *Science News* and the weekly supplement (Tuesday) of the *New York Times* can get you started on current topics. If you are writing a more sophisticated paper for a junior-senior course, you should go directly to the recent issues of the more scholarly scientific journals intended for professional scientists, for example, the prestigous weekly journals *Science* and *Nature*. In addition, scientific disciplines have their own specialized journals. For a discussion of these publications, see the natural science section of chapter 4.

FIGURE 14.1
(on facing page)
Comments produced by a methodical second-semester sophomore biology major seeking a paper topic in vertebrate physiology. The comments assume two semesters of general biology, one semester of cell biology, and a semester of comparative anatomy. [*Contents page from* Science, *vol. 197 (16 Sept. 1977). Copyright © 1977 by the American Association for the Advancement of Science.*]

As you consult the table of contents in a recent issue of an appropriate journal, you will see articles that can serve as the basis for good paper topics. If you are using a journal written for professional scientists, it is especially important to be patient and thorough, for interesting articles are often obscured by titles made up of technical terms and cautious wordings. For example, one student read carefully the table of contents from *Science* (figure 14.1). Rather than skim scores of titles, this student decided to dissect a few, and gained for his efforts some good possible topics that might have been passed over by a student who could not get beyond the difficult first reading. Here in figures 14.2, 14.3, and 14.4 we illustrate three of these dissections, and we evaluate the potential of each title as a source for a paper topic.

Careful reading of the title in figure 14.2 indicates that this paper concerns a blood test for alcoholism. An understanding of the exact chemicals measured is not important to the overall concept, although

...al gland" — function discussed
...hysiology — timekeeping is a
...icult concept. POSSIBLY, BUT
... IF NOTHING EASIER

...holism" — an interesting
...cal topic. Sounds like it
...COMMON INTEREST.

...ean" — sounds like ecology or
...t physiology. WRONG TOPIC.

...thyroid hormone" — function discussed
...hysiology — but aluminum not
...ioned. POSSIBLY, BUT ONLY IF
...HING EASIER.

...nabis" is marihuana plant; Δ9-tetra-
...ocannabinol is an important
...edient in marihuana. This topic
...tainly has COMMON INTEREST !!!
...D TOPIC

...ato sensory neurons" — obviously a
...rophysiology topic. Neurophysiology
...

ocean waves? Sounds like geology. WRONG TOPI...

"carrier" indicates cell bio. or biochem. topi...
"membrane" indicates cell bio. TOO HARD!
TOO SPECIALIZE...

? !!! ? hormone ! ? neurophysiology neuroanatomy

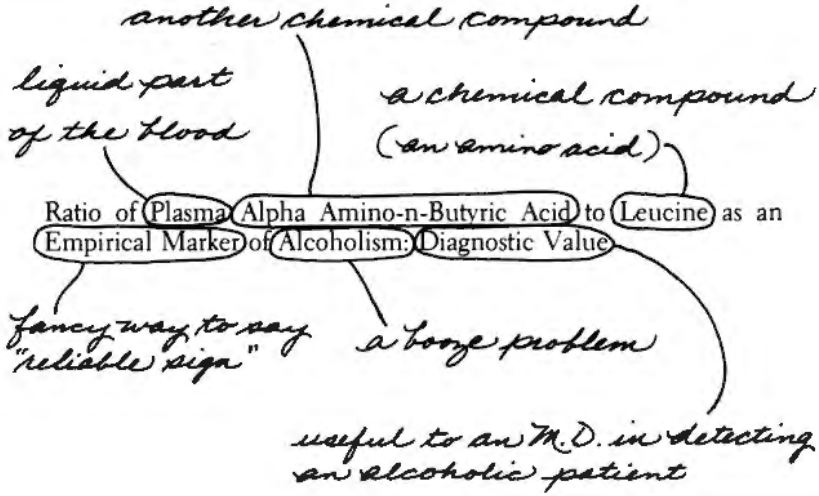

FIGURE 14.2
Analysis of title of article about alcoholism.

these happen to be rather simple organic molecules that most students with a year of chemistry recognize.

In figure 14.3 you probably realize that Δ^9-tetrahydrocannabinol is the major active ingredient in marihuana. You also recognize estrogen as an important female hormone which acts upon the uterus. This article explores a relationship between the two compounds, a topic of personal interest to many students and a topic that has been covered in the popular press.

The article described in figure 14.4 obviously requires some back-

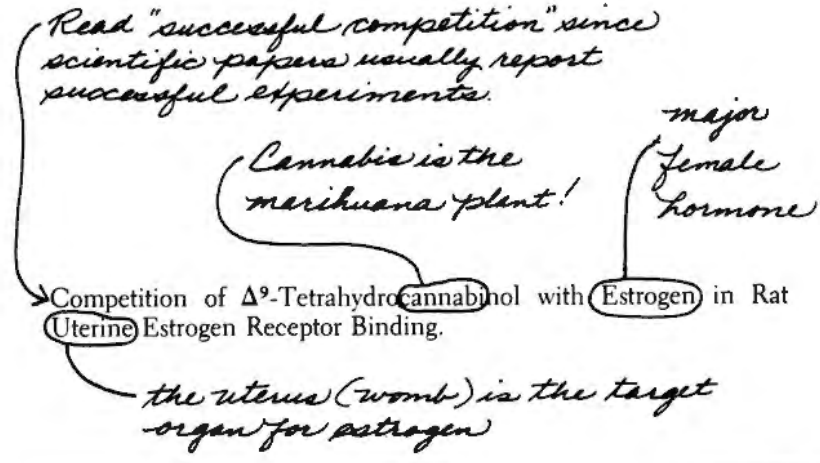

FIGURE 14.3
Analysis of title of article about marihuana-estrogen relationship.

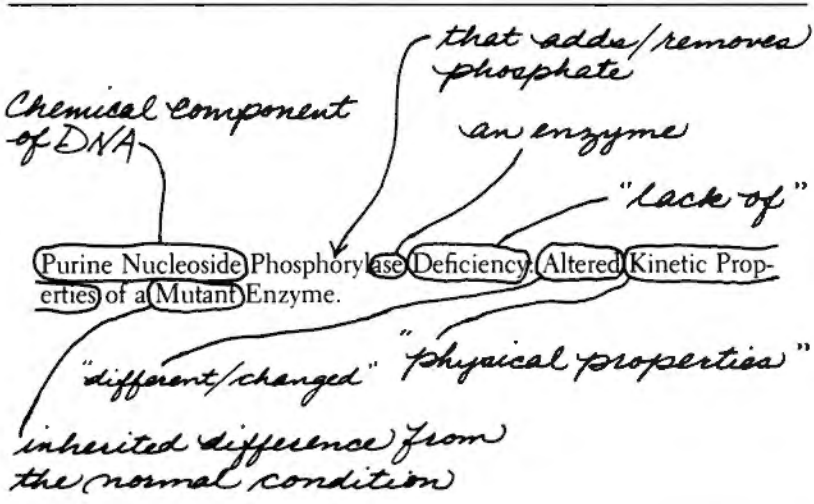

FIGURE 14.4
Analysis of title of article about DNA.

ground in biochemistry before it can be readily understood. If you are writing your review for a biochemistry course, this topic could be very productive. However, if your audience is less advanced, you will have to provide a minicourse in biochemistry before you can even begin to discuss this topic.

It is very useful at this point to try to write out in your own words the topics that interest you. The purpose of such an exercise is to make sure that you are clear on their meanings and to provide the occasion to write down your initial reactions. For example, a student considering the second article might write the brief note shown in figure 14.5. Such notes can be referred to later if other topics do not work out, and can be understood much more readily than if you had to begin again to look at tables of contents.

If, after careful analysis, the article looks interesting, your next step is to go to the article itself. Read the abstract and the introductory section. If they are filled with words that are unfamiliar to you and concepts that you do not understand, you should consider finding another topic, for you might spend too much time simply trying to learn enough to allow you to do the research for your paper. The abstract should give you a good understanding of the whole project, thesis, and results. The introductory section should give you, in more detail, some background information on recent research, so if you decide to work on the topic, the introductory section will be useful as a framework and guide for your own research. You will need, of course, to expand and to simplify the material, but this overview of a standard research work can provide you with a basic outline of what your paper might be like. Figure 14.6 shows the introduction of the marihuana article with comments by a student evaluating its usefulness for a possible outline of his own research paper.

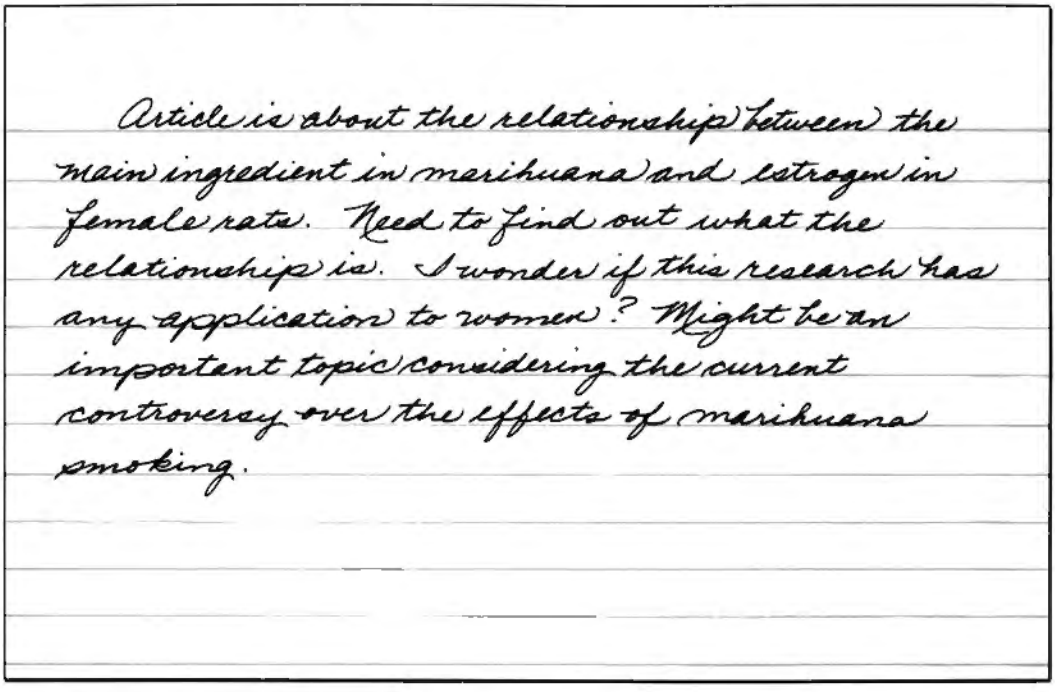

FIGURE 14.5

Notice that in addition to obtaining additional references to consult, this student has begun to formulate questions that can be the basis for his own paper. It is important in this generative stage to think in terms of questions, for ultimately you are going to have to develop your own framework for your research paper.

In deciding whether the article does provide material for your paper, you should consult the final section of the article, usually called the discussion section. This section, again in more detail than the abstract, provides the conclusions as well as further references that might prove useful. Figure 14.7 shows how the student used the discussion section from the *Science* article to add to his own preliminary outline.

Using the bibliography in your textbook

Another good starting point in your search for a suitable topic is your course textbook. Almost all upper-level textbooks in the sciences give references to the research reports and review articles that were used in writing the book. Read the reference lists and select articles that can serve as the basis for paper topics.

When you use this strategy for topic selection, you can be certain that you have chosen an important and appropriate topic. Also, the textbook will explain how the topic relates to the other subjects discussed in the

course. However, you will still have to discover if the topic is an area of active research, and you will have to find up-to-date information on the topic.

You can locate recent research reports on your potential topic by using an indexing service like *Science Citation Index*, *Biological Abstracts*, or *Chemical Abstracts*. See chapter 4 for a more detailed discussion of these materials. A lack of recent research reports indicates that you have chosen a no-longer-active topic, and you should probably try again.

Updating and simplifying a professionally written review

Because you are writing a scientific review paper, it may already have occurred to you that you might look at professionally written reviews to get some ideas for good topics. As we suggest in chapter 4, you should begin by locating the annually published review series that specializes in your discipline. These professionally written scientific review articles are more comprehensive and complex than the review you have been assigned to do, so after deciding on an interesting looking article, use the subheadings to help you limit your topic. Usually one or two sections will provide enough material for your review. Next summarize the information in the section you have selected, using the suggestions in chapter 5 on how to summarize without plagiarizing.

Although the professional review will give you an organizational pattern, your eventual addition of background information and up-to-date research developments should transform the organization into something clearly your own. Since any published scientific review article will be at least two years out of date, you must still search for the most recent research reports on your topic. As discussed in chapter 4, a forward search using *Science Citation Index* or a subject-oriented search using an appropriate index like *Biological Abstracts* or *Chemical Abstracts* will locate these reports for you. Although the information in these up-to-date research reports should dominate your review, you must connect this new information to the pertinent background material.

You may have noticed by now, if you have read the chapters on research papers in the humanities and social sciences, that topic selection in the natural sciences is based much more on a survey of the literature than on invention devices. Your topic must be current, and it must be the object of enough research to allow you to write about it. However, once you have identified a topic area, your responsibilities are those of any writer in any discipline: you need to narrow and define the topic so that it becomes a real question that you address and not just a broad subject. If, for example, you have decided on the topic of marihuana, you should pose a question about the subject. You need a controlling question that will provide direction to your research and organization for your paper when you are ready to write. Questions, such as the ones listed below, allow you to view your topic from a variety of perspectives, one or several of which might provide the framework within which you can work.

MAIN POINT

I. Background Info?

II. Does Δ⁹THC have a feminizing influence?

A. Human
1. ♂
2. ♀

B. Rats
1. in vivo (in living rat) ♂ ♀
2. in vitro (in test tube) ♂ ♀ – this paper

III. Does Δ⁹ THC cause cancer, esp. in women?

IV. Is Δ⁹ THC dangerous to babies?
A. Before birth
B. While nursing

What's this?

Competition of Δ⁹-Tetrahydrocannabinol with Estrogen in Rat Uterine Estrogen Receptor Binding

explanation required

Abstract. *Direct competition experiments with Δ⁹-tetrahydrocannabinol (Δ⁹-THC) and estradiol in binding assays with rat uterine cytosol estrogen receptors showed that Δ⁹-THC was a weak, but nevertheless significant, competitor for binding to cytoplasmic estrogen receptors. These data support, at the molecular level, the observations that Δ⁹-THC has a weak estrogenic activity (at least the ability to bind to estrogen receptors). Moreover, estrogen-like binding suggests that Δ⁹-THC, acting at the level of estrogen receptor, causes a primary estrogenic effect rather than an indirect or secondary phenomenon.*

INTRODUCTION

There has been increasing speculation (*1*) and some experimental support (*2, 3*) for an estrogen-like biological activity associated with heavy, long-term marihuana smoking in man and with the administration of Δ⁹-tetrahydrocannabinol (Δ⁹-THC) in male rodents. Because most of the data have been obtained from experiments in vivo where specific hormone-sensitive organs were examined for stimulation (*2, 3*) or repression (*4*), the conflicting results may be due to indirect effects in the whole animal.

The reports of uterine stimulation in castrated female rats by Solomon *et al.* (*3*), and of lowered levels of luteinizing hormone, follicle-stimulating hormone, and testosterone in men by Kolodny and co-workers (*2, 5*) after the long-term administration of Δ⁹-THC have also focused attention on the estrogenic nature of the drug. Since it has been demonstrated that Δ⁹-THC may be transferred across the placenta to the developing fetus (*6*), and that it appears in the milk of lactating animals (*7*), the question of deliterious effects on fetal and newborn offspring must be addressed. Estrogen and estrogenic compounds may play an important part in the development of several forms of carcinoma in human females and their offspring (*8, 9*), and they are potential suppressors of male hormones and of androgen-dependent tissues (*4*). Moreover, it has recently been reported that 4S estrogen receptors occur in both human prostate (*10*) and rat testes (*11*).

To test the hypothesis that Δ⁹-THC acts as an estrogen in a direct experiment, we have examined the extent to which Δ⁹-THC competes with estrogen for sites on rat uterus estrog[en] in vitro. We have also experiments wit[h] rat uterus por[tion]

same journal (Science)

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OK! 4S is explained in the method.

Science

FIGURE 14.6 (on facing page) *The introduction of an article from* Science, *showing how it has been used to generate topics and subheadings for an undergraduate scientific review paper. [From Allen B. Rawitch, Gregory S. Schultz, Kurt E. Ebner, "Competition of Δ^9-Tetrahydrocannabinol with Estrogen in Rat Uterine Estrogen Receptor Binding," Science, vol. 197 (16 Sept. 1977), pp. 1189, 91. Copyright © 1977 by the American Association for the Advancement of Science.]*

- What are the (mathematical, physical, chemical, astronomical, geological, biological) characteristics of X?
- Into what general category does X fit?
- How is X similar to or different from Y and Z?
- How is X related to A?
- What are the theories about X?
- What is the state of knowledge about X?
- What remains to be discovered or resolved about X?
- Why is X important to humans?
- What is the history of X?
- What are the ethical implications of X?

When you begin your research, such questions can provide categories for your notecards. These categories can be dropped, changed, or added to as you research, but in doing so you have to make conscious decisions which will help you to formulate plans for your paper. Your goal is to move from a broad topic to a one-or-two sentence controlling question. Table 14.1 provides examples of this movement, using the marihuana-estrogen problem. The rows in this table show how the topic of marihuana would be treated in the scientific fields of biology and chemistry as opposed to the way the topic would be treated in fields in the social sciences and humanities. Focusing on the ethics, history, or politics of marihuana use is interesting, important, and appropriate to courses in philosophy, history, or political science. We want to underline the point that only certain questions provide an appropriate focus for hard-core science courses.

Searching for a topic properly takes a great deal of time, but it is time well invested, for your search also produces an abundance of notes on the articles you read. These notes should consist of summaries—accounts that are written in your own terms but are nonetheless completely consistent with the articles. You need not hunt for quotable passages, for scientific review papers do not usually contain direct quotations. Instead, you should paraphrase or summarize all pertinent information. See chapter 5 for a review of these skills. When it is time to write, you will be able to incorporate some of these summaries directly into your paper.

After you have arranged your notes according to the questions that you asked of each article, you should be able to draw out an outline or an organization for your paper by using your questions ("What is the history of X?") as subheadings. By transforming questions into statements, you might come up with a tentative structure like this:

```
1. History of the marihuana-estrogen
   relationship: male heavy users developed
   breasts, etc. (female sex characteristics);
```

Taken together, our data demonstrate the capability of Δ^9-THC, and to a lesser extent 11-OH-Δ^9-THC, to compete with estradiol for binding to cytoplasmic estrogen receptors. The ability of the drug to occupy estrogen receptor appears to be limited under the conditions reported here (a maximum of 22 percent of the specific binding sites). It is clear, however, that the compounds responsible for the primary psychoactive effect of marihuana show significant estrogenic binding affinity.

These findings are opposite to those reported by Okey and Truant (*16*) who used a cannabis resin preparation to examine Δ^9-THC inhibition of estrogen binding to cytosol receptors. We have no explanation for their failure to observe competition between their cannabis resin preparation and estrogen receptor. These workers also reported that their cannabis resin had no effect on uterine weight (*16*) and, more recently, Okey and Bondy (*17*), using pure Δ^9-THC, obtained a similar result. It may not be appropriate to compare the effects of pure Δ^9-THC in vitro with those observed with cannabis resin (a mixture of many cannabinoid compounds and related natural products). Moreover, both Solomon *et al.* (*3*, *18*) and Shoemaker and Harmon (*19*) provide data consistent with our observations.

While the demonstration of chemical binding to estrogen receptors (as judged from competitive displacement and direct binding experiments) is not, in itself, sufficient evidence to prove estrogenic activity in the full biological sense, recent reports by Solomon *et al.* (*3*, *18*) of a uterotropic effect of Δ^9-THC in castrated female rats and by Kolodny *et al.* (*2*) of lowered testosterone levels suggest that this competitive binding may have biological significance.

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II. Does Δ^9THC have a feminizing influence?
A. Humans (book)
1. Males – Kolodny et al., 1974; Kolodny, 1975
2. Females –
B. Rats
1. In vivo (inside living animal).
a. male
b. female – Solomon et al., 1976 Science
but Okey & Truant get opposite result
2. In vitro (outside animal, using cell extracts)
a. male – prostate and testes have estrogen receptors, even though they are ♂ sex organs.
b. female – Rawitch et al., 1977 – this paper
→ get opposite result ← Okey & Truant, 1975; Okey & Bondy, 1977
Solomon et al. 1976, Solomon et al. 1977 agree w/ Rawitch
Shomaker and Harmon, 1977 agree w/ Rawitch

review structure and function of estrogen; also mention dangers of estrogen (cancer).
2. Biologically active constituent of marihuana Δ^9-THC isolated as active compound—show structure
3. Laboratory evidence that marihuana acts like the hormone estrogen in rodents
4. Laboratory evidence that marihuana acts like estrogen in humans
5. Medical significance of a marihuana–estrogen relationship, if indeed it does exist, including reduced male fertility, increased incidence of cancers especially in females, and possible damage to fetal and newborn humans.

FIGURE 14.7 (on facing page) *The discussion section of a research report in the journal* Science, *showing how it has been used to expand on a student's preliminary outline.* [*From* Science, *vol. 197 (16 Sept. 1977), p. 1191. Copyright © 1977 by the American Association for the Advancement of Science.*]

Writing the first draft

Developing a sense of organization is an important first step in molding a paper from research. To decide whether your research forms a complete paper, we suggest that you begin writing a first draft before your research is finished. Writing connected prose, sentences and paragraphs, gives you some idea of what a finished product might look like. Is your topic still too broad to be written about in the assigned number of pages? Is it too narrow to fill them? Are there gaps in your research or understanding of the topic? You can better answer these questions after you have tried various explanations and transitions to connect the parts of your research. Don't worry yet about language or spelling or any writing task that will deflect your attention from your purposes in writing this draft.

The advantage of writing a paper that is organized according to subheadings is that you can begin almost anywhere, for in most cases, these sections are independent units. The summaries in your notes can provide the beginnings of your draft; you can usually expand them or insert them at appropriate points as you develop each section.

Because of the nature of note taking for a review paper in the sciences, some students prefer to cut and paste a first draft. In fact, you can take a scissors to the notes that you have just accumulated and use them directly as part of the draft. Leave space for connecting paragraphs or instructions to yourself about what is needed to tie your summaries together. But whatever procedure you choose for the writing of your first draft, you should write out the body of the paper while you still have time left for more research if needed. Leave the introduction and conclusion to be written later.

In writing about the marihuana-estrogen relationship you could group together all research reports that tested the effects of marihuana (either the active ingredient THC or the THC-containing marihuana resin) on

Field	*Much too broad*	*Too broad*	*Still too broad*	*Controlling question*
Biology or chemistry	Marihuana	Effect of marihuana on human users.	Damaging physiological effects of marihuana on human users.	What is the state of the research that suggests that the active ingredient of marihuana, Δ^9-THC, acts like the female hormone estrogen?
Philosophy	Marihuana	The ethics of marihuana.	Ethics of marihuana experimentation on humans.	What are the ethical implications of studying the long-term effects of marihuana on human subjects who volunteer for such a study?
History of science	Marihuana	History of marihuana use in the USA.	The accumulation of evidence suggesting that marihuana has negative side effects.	A history of the marihuana-estrogen relationship.
Political science	Marihuana	Legalization of marihuana.	The relationship between medical evidence on the safety of marihuana and the legalization of marihuana.	What are the political implications of legalizing Δ^9-THC, the active ingredient of marihuana, if it is known to do serious long-term damage to humans?

TABLE 14.1
How the topic of marihuana can be narrowed to a controlling question in four disciplines.

whole rodents. Below is a student summary of such a research report which, in itself, is a good beginning for a draft section of a paper.

Okey and Truant (1975) tested on female rats the effects of a cannabis resin which presumably contained the active ingredient THC. They found no estrogen-like stimulation of the uterus of these rats: 1. the uteri of cannabis-treated rats weighed the same as untreated control rats, and less than that of estrogen-treated rats. 2. the estrogen-receptor molecules found in the

cytoplasm of uterine cells had not been occupied by a marihuana–resin molecule (such as THC) in the resin–treated rats and could still attach to a normal amount of estrogen.

This passage can be built into a draft in several ways. In this case, the student chose to paste the passage to a sheet of paper and to go on with a note about what he might add to expand the passage. In the note to himself, reproduced below, he also prepares to add the next summary to his expanding draft.

Use illustration in introduction to explain the concept of binding; also maybe a diagram of cell to show location of cytoplasm and the concept of cytosol. Here, go on to summary of a follow–up experiment to the one above.

Okey and Bondy (1977) tested the effects of pure THC on female rats. Again they found that the....

After you have pieced together the body of a complete paper, ask one or two friends, preferably ones in the same course, to read it, provided that such a practice is allowed in your school. Tell your readers to ignore grammar and other surface features, and to read for total comprehension. Do they understand what you are writing about? Is the background information useful in understanding the paper? Is the importance of the research clear? Discuss the paper with them and decide which of their comments should be incorporated into the revision.

Revising

You should plan to make major changes in your first draft before you submit your paper for evaluation. If you limit your revising to correcting grammar or sentence structure, you will miss an opportunity to do other important reader-oriented tasks. Remember, you are writing your review paper for an audience of science undergraduates who require thorough explanations of unfamiliar terms, careful transitions so that they can follow the research, and, perhaps, diagrams to illustrate difficult concepts or structures. Your revising responsibilities must include everything that will help your audience to share your understanding of the problem.

Most of the tasks discussed in the revising sections of the other chapters in this book apply also to the science review paper. You should look particularly at chapter 9 for advice on the use and abuse of technical language and passive voice constructions. Also, you should strive for effective transitions to guide your reader through the complex, sometimes unfamiliar words and concepts that are so common in the sciences. But

there are some special features of style and format that you should give particular attention to in this type of paper.

Tone of the paper. Your purpose in writing a scientific review is to inform your readers, not to persuade them. To accomplish this goal you must write with authority. Authority comes not only from the sources you cite, but also from your own confidence in your understanding of the subject matter. This confidence is conveyed in your skillful, dispassionate presentation of the material. The appropriate tone for a science paper is formal. The use of "I feel" or even "I think" is out of place in this kind of informational paper.

Use of subheadings. Most review papers have at least three subheadings, and it is common to have additional divisions within the subheadings. Conventions govern the placement of subheadings, so you should ask your instructor how they actually appear in a paper in your discipline. One common form of subheadings appears as follows: major subheadings appear in the middle of the page with the initial letter of each word capitalized; subheadings under these appear at the left-hand margin and are underlined, again with each initial letter capitalized; the next category is indented from the left-hand margin and in this instance only the first word of the subheading begins with a capital letter, while the whole subheading is underlined. See the example below:

A Centered Main Heading

A Flush Side Heading

An indented paragraph heading

Scientists are purposeful readers. They like to be able to locate and relocate particular information quickly. Titles for subheadings should be brief and informative. When you check the titles of each subsection, make sure that the material in each section belongs there.

Illustrations. Another characteristic of scientists is that they like illustrations and diagrams. These provide quick visual reference for subjects that would be difficult and cumbersome to describe in prose. Check to see if you can clarify any part of your topic by adding a visual representation. For example, on the marihuana-estrogen topic, your final paper could usefully include a drawing of an estrogen molecule (obtained from a table of steroid hormones in the *CRC Handbook*), and the tetrahydrocannibinol molecule (obtained from the *Merck Index*), so that your readers can see the similarities in structure. When you use illustrations, always refer to them in your writing to alert your reader to their presence.

References cited section. Instead of a bibliography that includes works on the topic, scientific papers have a section entitled "References Cited." For the proper format of scientific citations and the reference section, see chapter 5.

Other revision strategies. If, as you revise, you begin to wonder about

the appropriate level of complexity for your audience, consult several *Scientific American* articles. These articles demonstrate how to move your audience of fellow undergraduates up to the level of complexity required by your topic. Your textbook will also demonstrate how to present complex material to an audience with a limited background.

When the body of your paper is satisfactory, you should write your introduction and conclusion. These are best left until last to insure that they reflect accurately the final version of your paper. Remember that we have advised you in your own reading to focus first on the introductions and conclusions of articles. Your reader may decide to read your paper in the same way. These are important sections and must be written carefully so that the rest of your paper is put in the correct perspective.

The introduction may be theoretical, setting out the problem, or it may recount recent research which has raised questions about earlier assumptions on your subject. Whatever it covers, it should establish the importance of the subject and point the way toward your emphasis in the paper. An introductory paragraph on the marihuana-estrogen relationship based on the outline shown above might begin:

```
A possible relationship between the
physiological effects of marihuana and the female
hormone estrogen was first suggested in a report
by Harmon and Aliapoulis in 1972. This report
noted the development of female secondary sex
characteristics in adult male humans who were
heavy users of marihuana. These characteristics,
which paralleled those induced by the female sex
hormone estrogen, included enlarged breasts and
reduced fertility. Since these reports, the
possibility that marihuana might have estrogen-
like properties has been pursued in the
laboratory both at a physiological and at a
biochemical level.
```

This paragraph sets out the problem and the nature of the research very succinctly and sets the stage for two types of discussion, of the problem itself and of the studies of the problem.

When you write your conclusion, you should begin by reminding your reader of the major research steps that you have described in the body of your paper. For the marihuana-estrogen topic, mention the original observations that marihuana had a feminizing effect on male humans and then briefly summarize both the physiological evidence, pro and con, that marihuana, or at least THC, has estrogen-like effects on estrogen-target organs, and the biochemical evidence, pro and con, that Δ^9-THC competes with estrogen for the same binding sites in target-organ cells. After summarizing, tell your reader what these experimental results

really mean and why they are important. You could comment on the increasing number of research reports from various laboratories testing the possible estrogen-like action of the active ingredient of marihuana. You could even mention how these results will be important in resolving problems about the use and legal status of marihuana. Again remind your reader of the dangers if, in fact, marihuana does act like estrogen. Here is the only place to consider the questions: Why is X important to humans? What is the history of X? What are the ethical implications of X?

Finally, you should remark on the problems remaining to be solved. For the marihuana-estrogen research there are two obvious problems: conflicting results and the possible damaging effects of both estrogen and Δ^9-THC. You should point out that these problems will have to be resolved through further experimentation.

When your paper is complete, proofread for surface errors. Be especially careful to put in symbols ("Δ") that are not on your typewriter. Proofreading is exceedingly important in a scientific review paper. Since scientists must be thorough and exact in the details of their laboratory work, scientists also expect the same precision in written work.

QUESTIONS

1 What is the purpose of a review paper in the natural sciences?

2 How does a review paper in the natural sciences differ from a research paper in the social sciences? How are they similar?

3 What are the most important limitations placed on you when writing a scientific review paper?

4 What are your special responsibilities when revising a review paper?

EXERCISES

1 Select and define a topic by using the methods discussed in this chapter and then test the topic by using the criteria given on page 283. Narrow the topic according to the guide on page 288.

2 Using the methods described in this chapter and in chapter 4, locate five up-to-date research reports on any one of the following topics:

a Can gorillas "talk"?

b How do birds know the correct destination when they migrate?

c What is a "black hole"?

3 Using methods that you did not employ in your original search, add two items to the list that you compiled for exercise 2. Which methods produced the best results?

4 Select one of the research reports from the list you compiled in exercises 2 and 3 and write a summary of it.

5 In 1977, *Science* published the article, A. B. Rawitch *et al.*, "Com-

petition of Δ^9-Tetrahydrocannabinol with Estrogen in Rat Uterine Receptor Binding." Using *Citation Index* and other methods explained in this chapter and in chapter 4, find several articles reporting research done since 1977 on the marihuana-estrogen similarity. Hint: You may find some research that casts grave doubts on the hypothesis that marihuana mimics estrogen in human males.