Writing the Chemical Paper*

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Barring any significant change in a long established pattern, half of today's chemists will write only one or two papers during their entire careers. Perhaps this is all to the good, since scientists and scientific papers have proliferated by a factor of ten for each doubling of the general population during the past 300 years.[1]

But, looked at another way, this could mean that half of the world's chemical literature will continue to be produced by only 15% of the world's chemists. Can it be that 17 out of 20 chemists do not conduct studies worthy of recording in the literature of their profession? Or is it more likely that many potential contributors to chemical knowledge are reluctant to communicate their findings in written form, either because of feared inability to do so or because of difficulties experienced in previous attempts?

Assuming that the latter is the case, let's look at the magnitude of the problem, as evidenced by the authorship of papers referenced in *Chemical Abstracts* over a goodly number of years. As can be seen from the right half of the curve in Fig. 1, 50% of the authors referenced at least once in *Chemical Abstracts* have produced less than three papers during their careers. Following the curve back to the left, we see that only about 25% have produced as many as 10 papers. And a scant 3% have written 30 papers.

These statistics, compiled by Derek J. DeSolla Price, chairman of Yale's Department of the History of Science and Medicine, offer serious food for thought to all who believe that widespread dissemination of scientific knowledge accelerates betterment of Man's lot in the universe. What we have at present is a situation in which 85% of the world's chemists report little or nothing of the work they do.

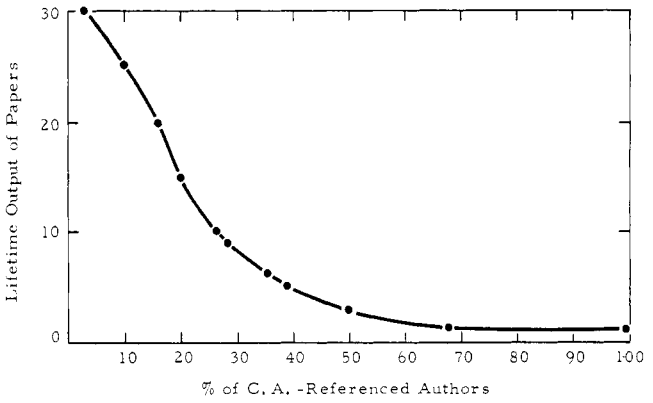

Fig. 1.—Few chemists write much.

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Are More Papers Needed?—In view of the logarithmic growth of scientific papers since Newton's day, should today's vast majority of nonwriting chemists be encouraged to publish their findings? And if they do so, will our chemical journals be swamped and their readers inundated by an ever-growing flood of manuscripts?

Personally, I regard this to be as wild and unfounded a fear as the current projection that, by 2025 or thereabouts, there will be no place left to stand except on another person's head. Already, science appears to be approaching the end of its 300-year period of adolescence and accompanying rapid growth.[1] Now we seem to be headed for a new phase of scientific development—a mature phase in which, percentagewise, fewer scientists will be needed to maintain or even accelerate the present rate of scientific progress.

In this new scientific era, fewer scientists will spin their wheels duplicating work already done or under way elsewhere. For, it is hoped, they will enjoy ready and substantially complete access to the entire world's then-existing body of published scientific knowledge. How this will come about—through new forms of primary publication, better and quicker abstracting, new methods of information classification and indexing, translations by computers, telephotographic transmission of papers requested from central repositories, etc.—is beyond the province of this paper. That it will come about seems an excellent bet, both because it is needed and because it can be foreseen, even if in imperfect detail.

The Chemist's Responsibility.—Although the future seems certain to provide adequate media for dissemination of scientific findings, individual readers will find no more minutes in an hour. Authors of chemical papers will have to compete ever harder for reader attention and, having gained it, tell their stories as clearly and concisely as possible. This has always been desirable; today it is becoming imperative.

At the symposium where this paper was presented, one speaker suggested that technical writers are fortunate in having a "captive audience" whose need to know will impel it to wade through murky writing in search of pearls that may lie hidden within. Some readers may, but most will not. The chemist who relies on this comforting hope may reach a few equally dedicated colleagues within the confines of his specialty. But chances are great that he will lose a majority of the audience potentially most important to him—the research directors and executives who must scan wide areas in order to choose from many ideas the few that seem to justify further investigation and development.

Before discussing the principles of clear technical writing, let's briefly review the reasons why chemists

have a responsibility to learn and apply them. Evidence has been submitted that: (1) only a small minority of chemists now publish their findings; (2) many more should do so, in order to prevent needless duplication of research and to accelerate worldwide chemical progress; (3) media for publication and dissemination will be available; (4) but, with more writers competing for the readers' time, clarity and conciseness will be more important than ever before.

Prerequisities for Clear Writing.—For the average chemist, confidence in his own ability is usually the only lacking prerequisite for successful authorship. By virtue of his formal education and professional experience, he should already possess the capacity for clear, organized thinking and a reasonably grammatical command of the spoken language. This paper will demonstrate that these are the *only* personal prerequisites required for clear written communication.

Steps Preparatory to Writing.—Norman Shidle, long-time editor of the *S.A.E. Journal*, has a favorite saying that packs a world of good advice in five brief words: "Clear thinking precedes clear writing."

First the would-be author must think his subject through carefully in his own mind. Then he should discuss it with his co-workers. Verbalizing one's thoughts and defending them before other qualified people is a valuable aid in formulating sound conclusions. And it helps the author form his thoughts into words that really communicate his ideas to others.

In drawing conclusions from his data, the author must, of course, be careful not to ignore facts that do not seem to fit a preconceived hypothesis. In such a situation, the hypothesis or the conclusions must be altered—not the fact. Older chemists may recall that general acceptance of Michael Polanyi's theory of adsorption was delayed more than 40 years because it seemed inconsistent with the electrical concept of interatomic forces.[2] Polanyi had experimental data, but his peers were unwilling to alter existing theories to fit the facts.

Thinking through one's subject and expounding it before one's peers is insurance against forming incomplete or faulty conclusions. This kind of clear thinking, which is by far the most important prerequisite for writing a good paper, should be fairly easy for a capable scientist—especially since he has not yet been subjected to the feared, brain-numbing step of taking pencil in hand. And once he has formulated his thoughts clearly, he should be ready to take that step with confidence.

Guides to Proper Form.—Before beginning to write, the author must decide the form in which to offer his ideas to his audience. There probably is no one "best" form, since a paper should be tailored to suit its intended audience. But since the printed instructions provided by technical journals are based on knowledge of the audiences those journals reach, they can serve as useful guides for decisions on form.

At Ethyl Corporation Research Laboratories, we have compiled many such guides for our authors to consult in deciding what form—and/or what journal—is best for conveying their ideas. Among those most useful to chemists are the American Chemical Society's Bulletin 8, "Hints to Authors," and its reprint, "Guide for Authors," both obtainable from ACS Headquarters. Also useful to chemists are the "Guide to Authors" and "Guide to Speakers," published by the American Institute of Chemical Engineers. In addition, many trade journals publish pointers for authors who hope to appear in their pages, *e.g.*, the "Author's Handbook," available from the Petroleum Refiner.

Outlining the Paper.—Most authors benefit from preparing some sort of written outline before starting to write a paper. For relatively inexperienced writers, the detailed "textbook" outline is usually best, since it forces them to think the whole paper through in advance. Such an outline, shown in part in Fig. 2, establishes a logical flow of ideas and subordinates supporting information under the main points the author wishes to make.

I. Introduction
  A. Nature of the problem
    1. State of art
    2. Unanswered questions
  B. Purpose of this work
    1. Scope
    2. Approach
  C. New findings
    1. Specific conclusions
    2. Resulting hypothesis

Fig. 2.—"Textbook" outline.

A complete "textbook" outline would consist of similar breakdowns for each of the paper's main sections. By showing the order in which section is to follow section, as well as the detailed breakdown of each section, the "textbook" outline serves as a blueprint for writing the entire paper.

Provided the author is a fairly experienced writer, a topical outline, such as that in Fig. 3, may prove adequate, especially for brief papers or articles. This consists of jotting down words, phrases, or sentences representing each main idea to be covered. When arranged in a logical order of presentation, such a list may be all that is needed to guide writing of the paper.

New chemical reaction discovered
Properties of the products
Use: mfg. broad family of antioxidants
Chemistry involved; equations
Possibilities for commercial process
Tentative economics

Fig. 3.—Topical outline (word–phrase–sentence type).

Hang Paper from a "Peg".—Ideally, the first sentence of a paper or an article should express the one paramount idea of the whole piece of writing. Norman Shidle calls this the "peg sentence" and advocates writing it before even beginning the outline. Thus, it will act as a guide and limitation for the entire written piece—and for the outline or framework on which all of the writing is built. In other words, it will serve as a peg from which to hang all the rest of the paper.

Figure 4 shows the peg sentence that was used in a research proposal directed to a group of biochemists and doctors of medicine, *i.e.*, to a highly specialized audience. A proposal to conduct research along the line specified stemmed naturally from this beginning.

The "peg" need not always be a single sentence. A "peg paragraph" composed of several short, simple

Knowledge gained since the discovery of π-bonding in 1951 makes possible previously untried approaches to synthesis of organometallic chemotherapeutic agents sufficiently similar to known metabolites to reach sites of biological action inside cancerous cells.

Fig. 4.—Peg sentence for specialized audience.

sentences may be required for clear and complete expression of a paper's theme. Certainly this would be true if, as in Fig. 5, the author was trying to explain the prospects for cancer chemotherapy to a nonspecialist audience—say readers of *Time* or *Newsweek*.

Chemists think they have found a way to fool cancer cells into poisoning themselves. They propose to do this by attaching toxic metals to the same compounds that normal cells feed and thrive on. Since cancer cells consume many times more food in their rapid growth, they will take in a lethal dose. But the normal cells won't get enough to do them any lasting harm.

Fig. 5.—Peg paragraph for wide audience.

Regardless of whether your "peg" is a sentence or a paragraph, it should set the boundaries for the entire piece. As Shidle puts it: "Reference to the peg should decide the fate of every fact and idea that knocks for admission to the writing. After the peg is established, the rest of the writing should flow naturally—almost inevitably. It will be amplification, exposition, definition, or other development of the idea expressed by the peg."[3]

Avoiding Unnecessary Complexity.—Even concepts that require specialized education for full understanding can and *should* be communicated through clear, concise writing. Recognizing this fact, a number of technical publications have hired professional clear-writing consultants to teach their staff writers how to avoid introducing unnecessary complexity into their stories.

One such consultant, Robert Gunning, the man who helped make the *Wall Street Journal* readable, has developed a handy yardstick for measuring and comparing the complexity of written material. Called the "Fog Index," it directly measures only two things: (1) whether average sentence length is so long that it may discourage or derail most readers, and (2) whether the mixture of long, complex words is too rich for most readers to absorb.

Indirectly, however, the Fog Index also forces authors to follow some important principles of clear writing: to prefer simple, direct sentences to long, rambling, complex ones; to use active verbs, rather than turning weak verbs into nouns that require additional weak verbs to complete a sentence; and, most of all, to write the way people talk, briefly and with force.

Computing a Fog Index.—To test the Fog Index of a piece of writing, we choose a representative sample containing at least 100 words. Next, we count and record the number of words in each sentence. Then we compute the average sentence length, which is one of the two factors needed for calculating the Fog Index.

Step two consists of counting the number of words of three syllables or more in the sample, omitting simple compound words like "manpower," verbs made into three syllables by adding "-es" or "-ed," and capitalized words like names of companies, equipment, cities, etc. Then we convert this count to percentage of polysyllables per 100 words, the second factor needed for calculating Fog Index.

Now, we add the average number of words per sentence to the polysyllable count per 100 words. Multiplying this sum by 0.4 converts it to the Fog Index—or the number of years of formal education required for reasonably ready comprehension of the piece of writing.

Nobody, Gunning least of all, cleains that a low Fog Index, *per se*, is a guarantee of clear writing. It is possible to use short words and short sentences and still be unclear. But a high Fog Index is a good indication that the author has introduced unnecessary complexity into his writing.

What is a Safe Fog Index?—Figure 6 shows the levels of Fog Index that graduates of various grades are able to read with reasonable understanding. But few people will allow themselves to be pushed to their limit for very long. Therefore, if we want to reach the most people—and have them understand what we are trying to say—it behooves us not to make our writing unnecessarily complex.

	Fog Index	By grade	By magazine
	17	College graduate	
	16	College senior	(No popular
	15	College junior	magazine
	14	College sophomore	this difficult)
Danger line	13	College freshman	
	12	High-school senior	*Atlantic Monthly*
	11	High-school junior	*Harper's*
	10	High-school sophomore	*Time*
Easy-reading range	9	High-school freshman	*Reader's Digest*
	8	Eighth grade	*Ladies' Home Journal*
	7	Seventh grade	*True Confessions*
	6	Sixth grade	Comics

Fig. 6.—Reading index.

"Quality" magazines, such as *Harper's* and the *Atlantic Monthly*, aim at people with superior educations. Thus, they can afford fairly high Fog Indexes. However, total circulation of the "quality group" is only about 1 million. On the other hand, *Reader's Digest* sells more than 13 million copies monthly. Despite the wide appeal of its subject matter, it could not maintain such a high circulation without being readily readable by the average person.

Since there are no brief synonyms for many chemicals and chemical processes, an author writing about them can reduce his polysyllable count only so far. To compete in Fog Index with *Reader's Digest*, the chemist would have to limit himself almost exclusively to very brief, almost telegraphic sentences. But he can and should write at a level only slightly higher than *Harper's* or the *Atlantic*—say a Fog Index of 13 or 14.

That chemists are able to express their most complex concepts in writing of no more than 14 F.I. is demonstrated in Fig. 7. The hatched bars show the average Fog Indexes of 11 of our chemists before Gunning taught them the principles of clear writing. As can be seen, eight of them, or 73%, were writing at a level of 17 or higher; *i.e.*, a difficult reading level even for college graduates.

Now let's look at the shaded bars showing the results

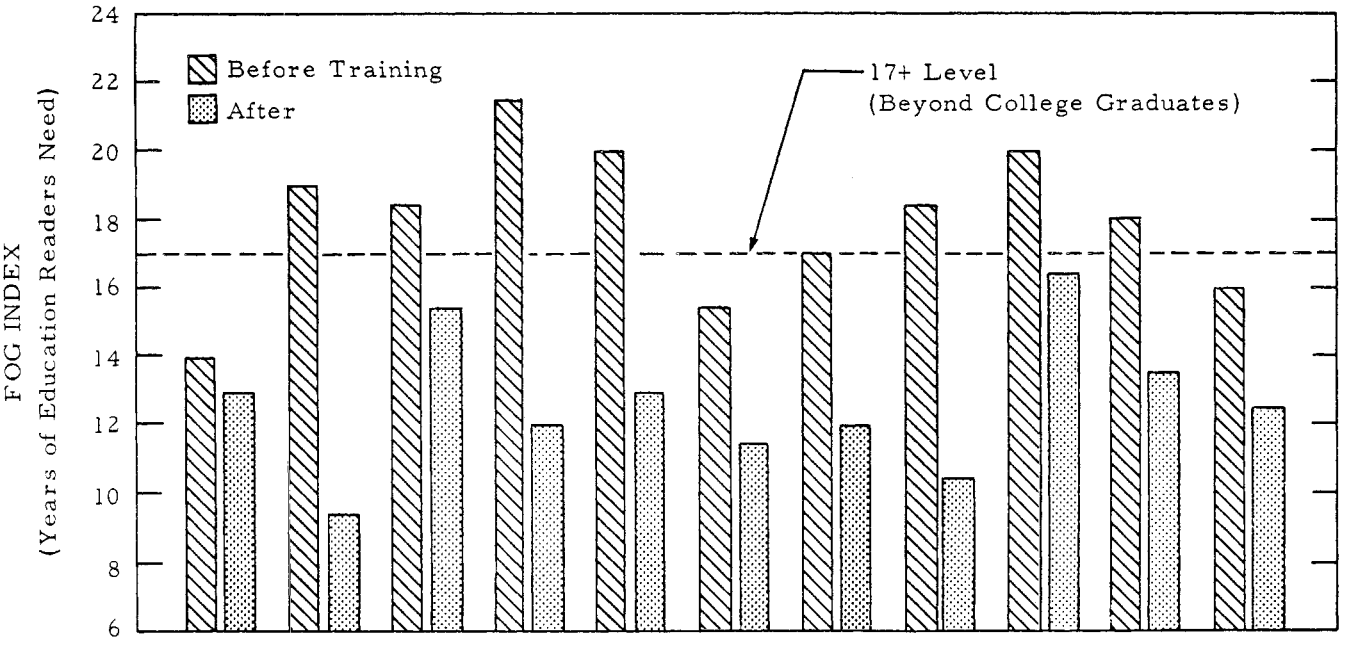

Fig. 7.—Readability of progress reports for eleven research chemists.

of the training. *After* Gunning's course, seven of the chemists (or 65% of them) were writing at or below the 13 level—or roughly the level of *Harper's* and the *Atlantic Monthly*. For the eleven-chemist sample as a whole, the average Fog Index dropped from an astronomical 17.9 before training to a mighty creditable 12.7 after training.

One chemist, the second from the left in Fig. 7, lowered his average Fog Index from 19 before training to less than 10 after training. He achieved this low average by skillfully intermixing short sentences (as brief as 5 words) with longer ones (up to 27 words). Prior to training, his average sentence length was 36 words. As would be expected from the nature of his subject matter, the training only slightly reduced his polysyllable count per 100 words—from 17 to 14. This reduction in polysyllables accounted for less than 15% of his great improvement in Fog Index. And despite the short average length of his sentences, his writing "read good—like a report should."

Principles of Clear Writing.—Space does not permit description of all that Gunning put into the Ethyl course in order to achieve these results. But we can examine the ten simple principles on which he bases his teaching.[4]

1. *Write the Way You Talk.*—People who have a good education and come from a family that speaks reasonably good English automatically observe most of the really important grammatical rules in their speech. Their spoken sentences have subjects, predicates, and objects—plus the interest-sustaining dividends of structural variety, color, and change of pace. The dangers of *not* writing the way you talk are that you may become textbookish, stiff, and so overly precise that you bore your audience.

2. *Keep Sentences Short.*—To maintain reader interest, sentences should vary in length and structure. But, on the average, they should be reasonably short. Writers who indulge in complex sentences containing multiple strings of phrases and clauses run the risk of getting beyond their grammatical depth. More importantly, short sentences give the reader time to absorb one idea before you confront him with another. Actually, there should be only one main idea in an entire paragraph. And that idea should be clearly stated in the first sentence of the paragraph. The following sentences should expand that idea, defining it further, giving supporting details, pointing out exceptions, etc. Then, to express the next main idea, you should start a new paragraph with another strong lead sentence.

3. *Use Active Verbs.*—What makes a sentence strong? In large part, it is the verb you use. Active verbs put action into writing. The dullness of most business and scientific writing stems from habitual use of the passive voice. Somehow the idea has spread that the passive voice is necessary for impersonal objectivity in reporting scientfic work. Beginning every sentence with "I" probably would seem unduly egotistical. But there is certainly nothing wrong with using "we" to denote the authors and/or their laboratories.

Where clear, concise reporting is imperative, as in on-the-spot sports announcing, you hear: "The fullback hit the line," not "The line was hit by the fullback." In business or scientific writing, you might expect to hear: "The hitting of the line is an activity engaged in by a player acting in the capacity of a fullback."

That's all wrong! The active verb "hit" has been made into a noun phrase, which then requires definition by a weak verb, "is," as being an activity engaged in by a fullback. The punch is gone, and sentence length has been increased.

Let's consider an example from chemical writing: "Present design is predicated on the assumption that atmospheric-pressure equipment is preferred by most chemists." The passive-voice verb forms, "is predicated on the assumption" and "is preferred by," total eight words. The same idea could be conveyed as follows: "At present, designers assume that most chemists prefer atmospheric-pressure equipment." The active-voice

sentence says in 11 words what the passive-voice sentence required 16 words to say. What's more, it is a more forceful, convincing statement, since it brings in the human element of people making decisions about other people's desires.

Converting chemical authors to use of the active voice would cut the volume of chemical literature to be read by about one-third. At least this seems a reasonable assumption from the example just cited. Can we afford to continue the use of passive voice?

4. *Use Terms Your Readers Can Picture.*—Unfamiliar concepts can best be explained in terms a reader can picture. Abstract, all-inclusive words may mean different things to different people. For example, what different feelings would the terms "democracy" or the "American way of life" evoke in Barry Goldwater, Jack Kennedy, Khruschev, and Mao? But you can hardly be misunderstood if you say, "A system in which leaders are elected by the people and the people are allowed to own personal property and operate businesses."

5. *Tie in with Your Readers' Experience.*—This is a corollary or extension of using terms your reader can picture. In explaining electricity to his son, many a father has compared voltage with water pressure and current with water flow. Readers can more easily grasp new ideas if you relate them to concepts they already known a fair amount about.

6. *Write to Express, Not to Impress.*—To communicate clearly, you must recognize the limitations of your audience and talk to them in their language, not in your specialized one—particularly not in scientific jargon intelligible only to a small circle of experts. Express your ideas as simply as you can. If they are worthwhile, the knowledge you communicate will speak for itself. Big men use little words; little men use big words. Here's a quotation from Einstein—than whom you can't get much bigger: "When a man sits with a pretty girl for an hour, it seems like a minute. But let him sit on a hot stove for a minute and it is longer than any hour. That is relativity." Expressive? Very! And note how it ties in with readers' experiences.

7. *Prefer the Simple to the Complex.*—Avoid using long, less familiar words when shorter, more familiar ones can convey the same meaning. Mark Twain said "I never write 'metropolis' when I get paid the same for 'city'." Note he said "paid," not "compensated." Check how many times you use "approximately" when "about" would do as well. And avoid long, complex sentences. They make readers backtrack to puzzle out what you meant to say.

8. *Make Full Use of Variety.*—Varying sentence structure makes writing more interesting to read. By beginning a sentence with a phrase or a clause, you can break the monotony from time to time. And don't be afraid to use an occasional long sentence where it fits your need. Mix a few long ones in with shorter ones. Just remember to keep down average sentence length.

Another way to add variety is to depart now and then from declarative sentences. Try the imperative, such as "Let's assume this situation. . . ." Or ask a question: "What would happen if. . . ?" Not only will this lend variety, it will also draw the reader into participating in your thought of development.

9. *Avoid Unneeded Words.*—These are semantic static that only weakens your message. Don't waste words through an indirect, passive-voice approach such as "It is recognized by experts that. . . ." Use the direct, active-voice approach: "Experts recognize that. . . " This saves words and gives your statements more force.

After you have written a paper, put it aside for a few days. Then edit it as if it had been written by somebody else—with an eye to knocking out as many words as you can without changing the meaning. Chances are that any changes you do make will clarify and sharpen the meaning as well as increase readability.

10. *Develop Your Vocabulary.*—First Gunning says to avoid unneeded words and prefer the simple ones. Then he says to develop your vocabulary. This is not inconsistent. We need words to think with—the more words we know, the more deeply and clearly we can think. And, as Shidle says, clear thinking precedes clear writing.

So learn the language of your profession and related professions. Learn to think in scientific terms. But when you write, always consider who your readers will be. Relate your thoughts to their experience. Think in your language, but write to them in theirs.

Coming to the Point Early.—Following Gunning's ten principles will help you express your ideas in clear sentences. Adhering to Shidle's "peg sentence" principle will prevent digressing from the point of your paper. One more admonition seems needed: Make sure you get to your point early in the paper.

The purpose of a scientific paper is entirely different from that of a detective story. In the latter, the author usually builds up suspense to a final climax. Readers of a chemical paper don't want to be mystified. They want to be informed. So define your problem briefly—then give the solution right away. Tell your audience what conclusions you have been able to draw and how they fit in with existing theories. If you do this early, those who are really interested will read on to find out how you did the work and why you think it is sound.

Knowing When to Quit.—Verbal diarrhea prolonged indefinitely is the curse of most authors—including this one. The best advice he can give is to quit as soon as you have covered all the main points you want to make. Sum up briefly if this seems necessary or desirable for reader retention of your message. But be as brief as you can. A short message is the straightest line between two minds—yours and your reader's. If he reads more than your summary (which, by the way, should be way up front), you have made a hit. Don't try to stretch it into an inside-the-park homer or you may be just another out.

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