Walden School finds that techniques often improve when a child becomes so fascinated by an experiment that he does it over and over again.

Must We Scrap Democracy?

I have suggested only a few of the ways in which early science experience can be made a vital part of every child's education. I hope that these examples may suggest the kind of elementary science teaching which should be an important part of our answer to sputnik. One of the immediate reactions to its launching was to lay the blame for our tardiness on democratic society. "Too much gabbing has been going on these days," Max Ascoli wrote in *The Reporter* last fall, "about the prospects—if not, indeed, the actual evidence—of the superior capacity a slave society has over a free one in getting things done." John R. Dunning, dean of Columbia University's School of Engineering, reminded us in an excellent article in the *New York Times Magazine* that "we should not be deluded into thinking that dictatorship is necessarily more efficient than liberty. . . . The voluntary principle is the very thing we are defending in the cold war."

If we reject, as most of us do, the notion of drafting scientists, we must find some better means of increasing our supply. Most of the current clamor for reform has been aimed at the upper levels of education. But high schools complain that students are not interested in science; colleges find them ill prepared. The widespread introduction in American schools of science teaching, democratically motivated by the interest and curiosity of younger children, would seem a made-to-order method for raising the level not only of our science education but of our culture as well.

Notes

1. An issue of the Ethical Culture Schools' publication, *School and Home*, for March 1930 reveals that at that time science had long been an important subject at all levels in these schools.
2. The students' choice does not appear to be motivated by parental interests, since Fieldston families represent a wide range of occupations and cultural backgrounds. Since a majority of the students are admitted in the primary or preprimary grades, where no intelligence tests are made, the factor of exceptionally high IQ ratings does not apply.
3. *Sci. Teacher* (December 1956).

Popularizing Science

Can it be done? One opinion is that very little of what scientists know can ever reach the public.

M. W. Thistle

"It is often said that the presentation of scientific results to the general public in assimilable form is an important task for our age, and so it is; but the best way of doing it is perhaps yet to be found."—Charles E. Whitmore [*Sci. Monthly* **71**, 337 (Nov. 1950)].

What scientists do, it seems to me, is to try to find out what is going on—either inside us, or outside us, or both. Scientists, then, are definitely set to eradicate mystery. Yet nonscientists, including some members of the popular press, tend to believe that there is something mysterious about science; that in consequence it is appropriate to regard scientists with awe, to praise them unmercifully, to laugh at them, to be afraid of them, or to consult them on questions that are not always framed in clear and answerable terms.

Nonscientists tend to believe that a scientific institution is swarming with eye-popping discoveries every Tuesday, most of which the scientists conceal because they are overcautious. Laymen cannot bring themselves to believe that most science is singularly undramatic; it is difficult to convince them that science is not a continuing series of spectacular advances, on all fronts at once.

Scientists, on the other hand, are very much aware that hundreds of scientists and thousands of engineers worked for a significant fraction of a century on the problem of nuclear fission. They feel that laymen must learn not to expect the same sort of spectacular success every week, in time for the rotogravure section; must learn that the progress of science is a slow creep, consisting of thousands of small successes; must learn that only now and then is a result achieved that is both dramatic and obviously meaningful to the multitude.

How did this situation come about? How is it that men who patiently try to remove as much mystery as possible, no matter how long it may take, are regarded as mysterious figures, crackling with sudden and frequent revelations of further mystery? Can it be that the task of talking about science to a lay audience is particularly difficult?

I have arranged a diagram of barriers to illustrate the situation (Fig. 1). The first barrier is a single one—man directing questions to the universe—but all of the other barriers are double: barriers inside the communicator plus barriers inside the communicatee.

I shall discuss first the possibility of giving detailed and accurate accounts and then the possibility of transmitting scientific attitudes.

First Barrier: Words versus Things

Here the problem is to record new information about what is going on in the universe, somehow in terms of human symbols. This relation between things-going-on and human symbology has fascinated me for years. In the present context, it is enough to note that this problem does exist and to remark that even the wisest words serve as rather poor maps of what is really going on.

Second Barrier: Language and Sophistication

Everyone is aware of the language barrier; most people are also aware that some few persons are much better than others at talking about science to laymen, and so they pin their hopes on these unusual people and trust that all will be well.

Mr. Thistle is chief of the Public Relations Office of the National Research Council of Canada. This article is reprinted, with permission, from March 1957 issue of the *Journal of the Royal Naval Scientific Service*.

However, even when you have found someone who is very good at talking about science to laymen—and a rare breed it is—all is by no means well. Other barriers exist that make the language barrier seem quite trivial by comparison. I shall review the language problem very briefly and then get on to consider stages of scientific sophistication.

Language barriers. For many purposes, English is a flexible and beautiful thing; I have been drunk on it many times, when it was used by someone who knew how to use it. But if English—or French or Chinese—had been suitable for science, we would not have been forced to invent a number of better languages *for scientific purposes.* For this job, English is hopelessly inadequate. Some of the scientific languages, such as that of organic chemistry, have more than twice as many terms as English (are twice as "rich") and are structurally superior in a quite dramatic fashion.

To ask a man to translate from one or several rich, relatively new, and precise scientific languages into a single poverty-stricken language of inadequate structure—with the built-in faulty science and outmoded thinking of previous centuries showing at every seam—is asking a very great deal. Whatever detail this man does manage to get across to a general audience will certainly be distorted and, to some extent, actually false. No other outcome is possible.

If you listen closely to a man who is supposed to be good at talking about science in English, you will notice that he is not trying to transmit many details—he is giving broad outlines, general trends, and a highly condensed abstract of results. If he really is good, he knows that scientific details cannot be transmitted in an undamaged condition to a lay audience, or even to a nonspecialist scientific audience.

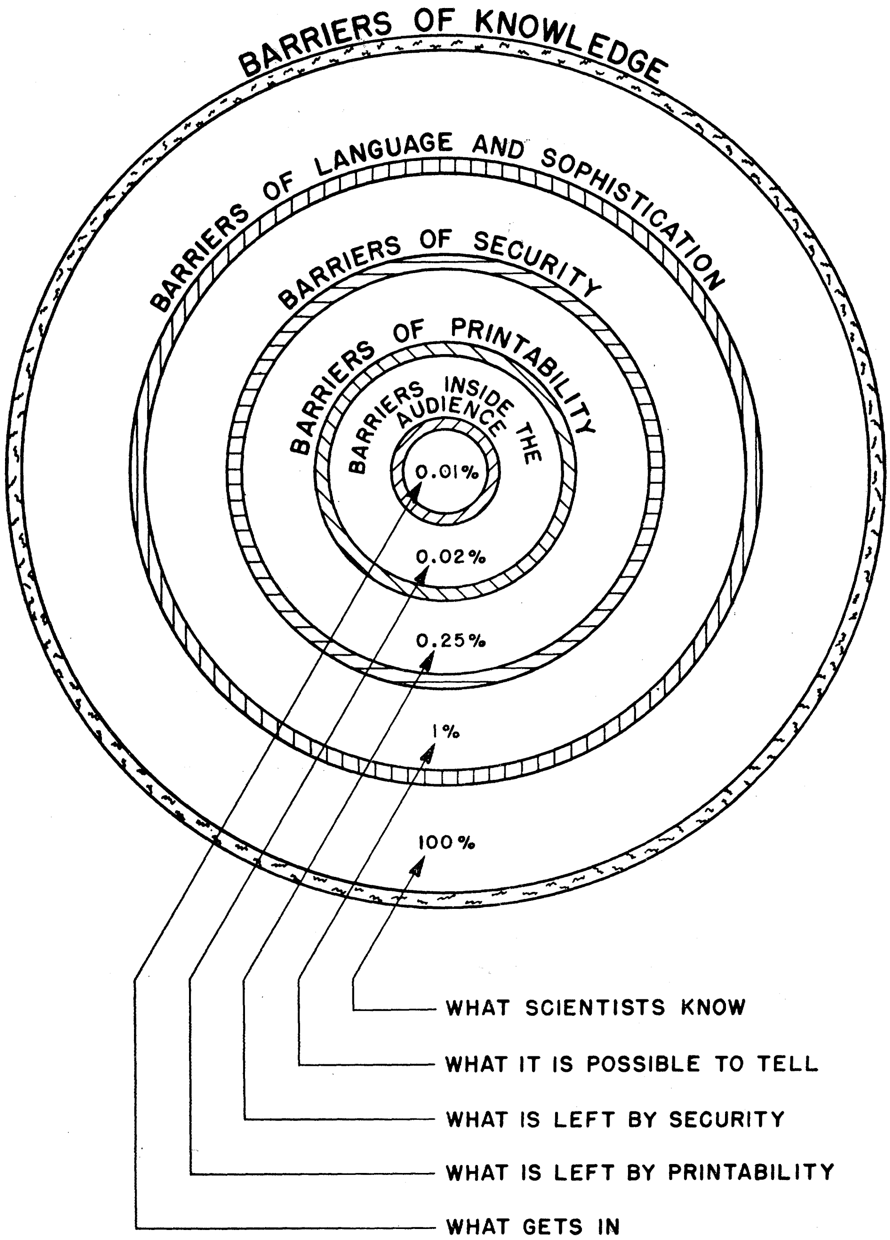

Fig. 1. Barriers to communication.

Laymen think it is quite natural for them to be ignorant of the scientific languages; it strikes them as unnatural when a scientist is ignorant of English. But as a matter of observation, only a very small percentage of *either* group is able to operate competently in the English language. Competent literacy is quite rare, and it is unfair to expect every scientist to be also a master of the common tongue. It would be astonishing if every scientist—or every butcher—were also an author in his spare time.

Rightly or wrongly, the language barrier is generally felt to be inside the scientist rather than inside his audience, and there is some justification for this view. I know a lot of scientists whom I love, but whose operations in the English tongue remind me of an elephant on stilts—ponderously inelegant. However, before we become too scornful of the scientist who is clumsy in English, let us have a good sharp look at the audience.

Stages of scientific sophistication. Gaston Bachelard, professor of the history and philosophy of science at the Sorbonne, in his book called *La Philosophie du Non,* gives a very useful listing of the five stages of scientific sophistication (Fig. 2):

1) *Primitive realism* might be stated, very briefly, like this: $x + y + god = 0$. If you are trying to understand something, but can't, you can blame it on the whim of a god, or perhaps on the work of a devil.

2) *Empiricism* has at least advanced to the notion of using measurements made with rulers, thermometers, and so on. Then you can say how hot it is without referring to Hell.

3) *Classical science,* typified by Newton, has advanced to the notion of using laws: the law of gravity and that of the relationship between temperature and pressure, for example.

4) *Modern science,* based on Einstein, has advanced to the notion of conversion: matter into energy, and so on.

5) Even Bachelard admits that *advancing science* is difficult to define. So far as I am concerned, advancing science, based on the notions of men like Dirac, tells us that we cannot even

imagine what an electron is like, but must use mathematics. It is the end of any sort of comfortable representation of "reality" but compensates with free-wheeling "worlds of 'if'." It closes certain things to our imagination and, at the same time, invites us to make much more use of our imagination. Confusing, isn't it?

Before we go any further, let us get rid of any idea that *value* is attached to these stages. None is to be despised. Any one of them is rich in its own right and *different* from the others, but it is *not* better than the others. Some of my dearest friends are almost pure "primitives" (stage 1 on this scale); the only book I have published is almost pure "stage 1," and I am not ashamed of it; I wish I were a better primitive than I am, and I have no burning desire to be a stage-5 man—I'm having fun where I am, mostly in the first three stages. Let me say it over again: these stages are *different*; they are *not* like certain soaps, better, period.

To me, the most important part of Fig. 2 consists of the upright bars between the various stages. It suddenly occurred to me that these barriers are real. To go from one stage to the next—through the barrier—takes a tremendous amount of effort and many years of hard study. That is why so few of us ever get into stage 5.

Recently we had a stage-5 man visit the National Research Council of Canada—Dirac himself. Dozens of stage-4 scientists stayed away from the lectures because they would have found them meaningless. For this man to try to tell *me* what he is doing (I am mostly stage 3) would have been like talking philosophy to a monkey. The monkey, of course, could never get onto this scale at all, and it is theoretically possible for me to reach stage 5 in about a quarter of a century of single-minded effort. But right now the comparison is just. Dirac is two barriers away from me (I used to be a scientist myself) and three or four barriers away from most laymen. The chance of his being able to communicate very much through all these barriers is not very great.

So, the language barrier inside the scientist makes communication of *detail* extremely hazardous; but the barriers inside the lay audience—these difficult barriers between the various stages of scientific sophistication—make the communication of modern scientific detail utterly and completely impossible.

It is all very well to look to the past and say, "Whathehell, Darwin did it."

Primitive realism	Empiricism	Classical science	Modern science	Advancing science
1	2	3	4	5

Fig. 2. Stages of scientific sophistication.

But Darwin was a stage-3 man himself, and he wrote for a stage-3 audience. Communication at this level is now within the scope of our high schools. We have added two more stages since Darwin—which is to say that we have added two more barriers.

You may remember a time when only a dozen men in the world understood Einstein, and all of them were in process of going through that barrier themselves. Einstein tried—and in my opinion, failed—to transmit stage 4 downward. I am stage 3, and I gave Einstein's "popular" writings a good honest try. I admit that I now know very little about the details of Einstein's theories, other than to parrot $E=mc^2$.

Concerning details. Very little detail can be transmitted back through even a single one of these barriers; through more than one, the task is hopeless. It is about time that we stopped expecting miracles of even the best exposition; you can get the same glassy stare by declaiming Gaelic poetry to a deaf sea gull. In this you would come up against four barriers: an unusual form (poetry); an unusual language (Gaelic); a defective transmitting mechanism (impaired hearing apparatus); and receiving apparatus so inappropriately trained for the job that it might just as well not exist (the cortex of a sea gull). So much for our chance of communicating scientific details.

Can we then say nothing? On the contrary, we can still say a great deal. One way of reaching down past the barriers is to find something familiar to everyone and talk about that. When Ray Lemieux synthesized an obscure carbohydrate called trehalose, the world of chemistry was jubilant, but the public did not care. However, a few days later he synthesized sucrose—the sugar you put in your tea—and now you have a story.

This is the old rule of writing: to go from the known to the unknown. The trouble is to find something that laymen think they know—something to hitch your story to. Wilder Penfield can talk about brain surgery to a fascinated audience because he hitches what he has to say to, for instance, the problem of bringing up children in a foreign language. You see, people generally have the illusion that they know something about children. Similarly, the bang of an atom bomb will make you listen to a description of isotopes.

When this point of common interest has been found, we have some hope of transmitting broad trends, general conclusions, and a few carefully selected results.

Third Barrier: Security

The barriers of language and sophistication obstruct communication of all but a very small amount of what the scientist knows—of all but perhaps about 1 percent. The third barrier, "security," obstructs communication of, at a rough guess, about three-quarters of what is left. Security exists in several forms. Military security accounts for a good many restrictions, but so does economic security: it is most unwise to reveal certain developments until after they are patented, and, beyond that, it is still unwise to reveal these developments before they have been actually adopted by an industry. Otherwise we are plagued by people who want to buy the thing: the general public confuses invention with business. Political security is also encountered.

Since all forms of security tend to involve applied science only, it follows that security attaches only to those items that are relatively easy to talk about; hence the high mortality.

Fourth Barrier: Printability

Items that survive the first three barriers have to compete for space in the public press against all other stories from all other fields of human activity. This means that the scientific story had better be important, and it had better be well written. Even then, a local fire or a major political, economic, or crime story can easily displace the scientific item.

Figures here are bound to be even more shaky than those that have already been given. I use 10 percent as the figure for survival across the barrier of printability because, if I send a story to

400 possible outlets, my average take is about 40 clippings. Of course it would be easy to choose 50 possible outlets and thus change the outcome. But 10 percent seems reasonable to me, in this context. In most of the 40 clippings the story has been cut to the bone, and beyond.

Incidentally, when reporters write their own stories, this figure is likely to be reversed. Their stories occasionally suffer from cutting or displacement but stand a much better chance of appearing in print than does a "government handout," coming through the mail. So it is wise to assist reporters to do their own stories.

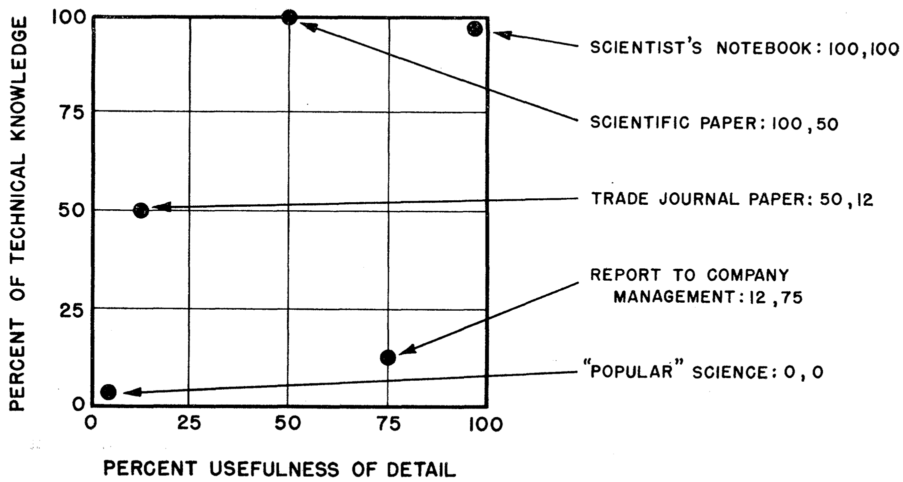

Fig. 3. Graph devised to help a scientist suit his material to his audience. One hundred percent of technical knowledge is, of course, 100 percent of what the scientist has to offer. No great accuracy is claimed for the points—they merely indicate the general area for each audience. [J. A. Anderson]

Fifth Barrier: What Gets In

It has been stated that the "average" newspaper reader will read one-fifth of the news stories in his paper. Against this we can set the fact that "several" people read each copy sold. But suppose we have finally captured a reader for one of our science stories. What is going on inside him?

Remember that, if I wrote the story, some of my own stage-3 language is probably still there, and the reader has his own barriers, with which it is quite probable that I have not dealt very expertly.

Some readers will no doubt understand every word; others may only be sitting there, performing eye-swivelling exercises. So, on the average, we can guess that about 50 percent of the story actually reaches home in the brain of the reader.

When we calculate what gets through all five barriers, it turns out that this is of the order of one ten-thousandth part of what the scientists know.

It may be only a ten-thousandth part of what scientists know, but this is still a fair amount; after all, scientists deal with information, and they have a tidy stock—about 60 million pages per year at the current rate of production.

However, it may be that the most important thing to transmit is something of scientific attitudes (sometimes called "the philosophy of science"), so we will now examine a few of these attitudes.

Scientific Attitudes

While scientists have managed to retain the sense of wonder and the intense curiosity of very young people, in other respects they have advanced to a maturity of outlook that might be valuable in other parts of our society.

Maturity of the scientific outlook. Maturity can be defined by what it is not: a mature person, in the sense I have in mind, is not dogmatic, is not damnatory, is not proud. A scientist does not say: "This is what I have found, and if you do not believe me, I will burn your body, and if you escape me, I will burn whatever survives of you in the hereafter." A scientist knows that the mistakes of Aristotle were replaced by the mistakes of Newton, which were replaced by the mistakes of Einstein. He is not interested in being "right"—only in finding out what is going on. To this end he invites criticism. And he really does not care in the least if the other person has a different color of skin, a different color of religion, or a different color of politics. All he cares about is the repeatability of the other fellow's results and any new light that is shed on the universe. Many scientists practice tolerance in their daily lives to a somewhat higher degree than is the case in most other professions.

To judge from what I see in the newspapers, this sort of outlook might well be useful to society in general.

In times past, the scientists' easy attitude with respect to "foreign" religions made the general public a bit uneasy and distrustful; people would have been more comfortable if their scientists had been a bit more intolerant. These days few people seem to care about religious tolerance, but they would be more comfortable if the scientist were more intolerant towards "odd" brands of politics. The fact that they have no cause for worry on this score is shown by the record of our scientists in World War II. A good many of them spent the war years in the front lines, testing their devices. The loyalty record of scientists compares favorably with that of any other large group. They are tolerant, but they are not stupid. Like any other intelligent group, they think that war is folly, but once it starts, you will find them lined up on their own side.

Scientists and the humanities. Every now and then you can still hear someone remark that our scientists ought to come out of their ivory towers, mingle with the populace, and become "more human." It has evidently escaped these folk that scientists *have* done just that, quietly and without any fuss, during the past decade or so.

In their communities, support for the arts and humanities now comes in generous measure from the scientists. You will find a large number of engineers, chemists, and so forth in the audiences of folk singers, ballet groups, local and imported theatre groups, and so on, and likely as not you will find some of them performing in semiprofessional symphony orchestras or, for that matter, even in amateur ballet. Some of them write fiction (you may recall a Canadian best-seller called *Sarah Binks,* written by a chemist); others paint; others take part in local government. In short, modern scientists make excellent citizens. The old idea that scientists are so deeply interested in their work that they invariably neglect their duty to the community is passé. In Canada, the arts and humanities have few better friends outside their own ranks than the scientists.

New responsibilities for scientists. Since science is becoming increasingly important in our daily lives and now touches us so nearly on all sides, the need for talk about science is on the increase. Scientists can expect to be subjected to increasing pressure to do some of the talking themselves. A great many of them are using public money, and it is not unreasonable to expect them to make an occasional "report to management."

It pains me to say so, but relatively few scientists are yet aware of the enormous importance of reasonable competence in their use of English. If they examine the five steps of the generalized scientific method, they will see that only one of these steps—making the actual measurements—does not involve the use of symbols. And this is the only step that they can leave to a technician; the *scientists* must frame the question and draw the theoretical conclusions. Language is their business.

Aside from their need of reasonably adequate English as an essential part of their written and spoken reports to one another, they will need English for communicating with laymen at various levels—for example, in the trade journal article, the "popular" speech, and the interview with the press. Some of them do these things very well indeed; but far too many of them do these things rather badly.

The ones who do it badly err on two counts: a bumbling, fumbling use of the language itself and a thoroughly mistaken idea of how much detail is required. There is no substitute for adequate training in writing and speaking, but it may be possible to give a quick insight into the amount of detail needed. The graph in Fig. 3, adapted from an original by J. Ansel Anderson, chief chemist of the Grain Research Laboratory in Winnipeg, may be helpful.

At the time this graph was prepared, neither Anderson nor I had heard of Gaston Bachelard. Nevertheless, we agreed that science for laymen was in the area of 0,0: zero technical knowledge and zero detail. Scientists please note.

Conclusions concerning attitudes. Some common attitudes of our scientists bother me, such as their persistent refusal to learn the techniques of communication—resulting, on the one hand, in some of the worst-written documents in the world and, on the other, in a firm belief that the press is out to misquote them deliberately.

Certain other attitudes of our scientists seem to me to be worth pondering: the desire to find out what is really going on, instead of being content with what other people say is going on; the determination to take no man's word, not even your own, for a material fact unless you can put it to the test and observe for yourself; the confident expectation that whatever you do will soon become outmoded and surpassed, and that this does not matter in the least; the expectation that other people will be markedly different from you, and that this is an excellent arrangement; the convictions that doing your best to think straight is a worthy occupation for a full-grown man, that this is a strange and wonderful universe whose ultimate secrets we will never quite plumb, that it is nevertheless the best sport in the world to try to plumb them, that you *never* get something for nothing, that you *always* get less than you expect—and that *never* and *always* are very dangerous words.

One way to spread these notions is for the scientists themselves to do a bit more talking; the attitudes will soon become apparent, no matter what the scientist is actually saying.

In conclusion, I might point out that we have some very old precedents for breaking through the barriers and talking to ordinary folk about extraordinary things. Jesus had such a problem. His technique was to put what he had to say into a perfect little short story, dealing only with familiar things that you can touch and see. He would begin with, "A certain man had two sons," or "Behold, a sower went forth to sow." To this day, the only device I know that will actually work for an audience of fishermen, taxgatherers, publicans, housewives, or other groups of laymen is this same technique of analogy, comparison, metaphor, simile, and parable.

Making Popular Science More Popular

Tested techniques of communication can help make the leading ideas of science clear to the layman.

John Pfeiffer

It is a pleasure to comment on M. W. Thistle's thoughtful and stimulating article, which comes as an important contribution to the continuing problem of bringing science to nonscientists. Two attitudes may stand in the way of those most actively concerned with communication in this area. There are still scientists who feel that the problem cannot be solved, that the layman does not have the mental equipment required to appreciate basic aspects of science, and that any attempt to communicate is an utter waste of time. They regard their colleagues' ventures into popularization as a mild form of corruption.

At the other extreme are the few scientists and science journalists who believe that they have solved the essential problem of popularizing science. Their monolithic complacency may annoy us, but it nevertheless deserves some sympathy. It is not always easy to live with the knowledge that one's writing and editing frequently leave much to be desired. On the other hand, insight and a fair share of humility may be helpful when it comes to setting higher standards and making a serious effort to meet them. I think it is reasonably evident by this time that higher standards are called for.

Thistle, chief public relations officer of the National Research Council of Canada, is neither frustrated nor complacent. Critical in a positive way, he indicates major limitations and then suggests that the situation is not as hopeless as it has been pictured. Indeed things could be a great deal worse, especially if we consider some of the things that are happening outside the laboratory.

Mr. Pfeiffer, a science writer, lives in New Hope, Pa.