nomic recession, reduction in funds for research and development, some unemployment among scientists and engineers, and increasing inflation. By 1975 and 1976 paid circulation had fallen to 137,000, but by 1979 was back up to 152,000.

The circulation is worldwide. In 1979, more than 14,000 subscriptions were regularly mailed to 141 countries other than the United States.

Other indicators of success can be found in various measures of usage. Requests for permission to reprint tables, figures, excerpts, or whole papers have increased steadily over the years and in 1979 over 7000 requests were granted. Also in 1979, 5000 libraries purchased microfilm copies of single issues up to runs of several volumes from University Microfilms. These sales ranked *Science* ninth among the 12,200 periodicals in the University Microfilm catalogue, following *Time*, *Newsweek*, *U.S. News and World Report*, and several other magazines. In a 1974 analysis, the British Library Lending Division reported receiving more requests for photocopies of articles from *Science* than from any other of the 15,000 periodicals from which photocopies were wanted (*2*).

In 1978, 59,000 citations to articles previously published in *Science* gave it seventh rank in total citations among 3463 science, social science, and clinical periodicals covered by *Journal Citation Reports* (*3*). In 1976, the Ladd-Lipset Survey found *Science* ranking fourth among periodicals read by American faculty members, and third (behind *New York Times* and *Time*) among faculty members at major universities (*4*).

Science writers and the public media also find *Science* useful. In a 12-month period of 1978–1979, stories credited to *Science* appeared in 70 magazines and newsletters and in more than 400 U.S. newspapers.

More than 30 indexing and abstracting services include material from *Science*, and it is the only technical journal indexed in the *Readers Guide to Periodical Literature*. In 1977, *Readers Guide* announced it was dropping *Science*, but received so many protests, especially from smaller libraries, that the decision was rescinded.

Like most journals, *Science* makes reprints available to authors and to others who wish to use them for classroom or other purposes. Reprint orders running into the thousands have occasionally been needed to satisfy requests for copies. Still the most popular reprint, almost a dozen years after its publication on 13 December 1968, is Garrett Hardin's "The tragedy of the commons."

That article also illustrates the fruitful collaboration that can occur between author and editorial staff. "The tragedy of the commons" was originally given as Hardin's presidential address to the Pacific Division of the AAAS. I did not attend that meeting, but after reading the printed version I sent him a complimentary note regretting that I had not heard his address. He wrote back saying I should have no regrets; thanks to the good advice of the editorial staff the printed version was better than the original.

Reprints, circulation figures, citation counts, and other numerical measures are all useful indicators of how effectively a periodical is meeting its objectives. But the real answer must be one of judgment. How best to try to meet those objectives depends on the judgment of the editorial staff. How well they have succeeded is for the readers to decide.

References and Notes

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Scientific Communication

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Those engaged in the pursuit and preservation of scientific knowledge are part of a great and lasting enterprise. Through the devoted efforts of a relatively tiny fraction of the earth's population, a marvelous edifice of knowledge has been created. Each day additions to the structure are made. Occasionally modifications or partial renovations are necessary, but the major features of the structure have stood and will continue to stand the tests of time, not for just a century but for the millennia.

It is unfortunate that the uninitiated cannot fully perceive the beauty of the structure, the intricacy and subtlety with which it is tied together, or the solidity of the foundations on which it is built. However, billions of people already have enjoyed some kinds of benefits from applications of science, as will countless billions in the years to come.

The key element in the building and preservation of this marvelous edifice is communication. Without communication there would be no science. Without archival preservation many values would be lost. Thus, on this centennial of *Science*, it is appropriate to consider trends in scientific communication.

Many of the qualitative patterns of verbal and written communication of present-day science were already established by the year 1880. For example, the scientific journals, though few in number, were similar in form to those of today. But quantitative aspects have changed greatly and new patterns, such as electronic storage of data, are beginning to emerge.

When the first issue of *Science* was printed, several scientific journals were being published in Europe but only one respectable publication, the *American Journal of Science*, was being published in the United States. There were few scientists and few were being educated here. The American Association for the Advancement of Science was a small but vital organization that held annual meetings and maintained a sense of community among scientists.

From 1880 on, the number of scientists being trained increased, as did the number of scientific societies and their publications. In 1900 about 100 doctorates were awarded in the natural sciences, and this grew to 11,000 in 1970. The number of scientific publications grew to be in the thousands, with a content of millions of pages. In 1880 it would have

The author is editor of *Science*.

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been possible for a scientist to scan—even read—the world's scientific literature and to be acquainted with all of the active research in the United States. Today an individual can only be aware of a small fraction of the contributors and their contributions. Faced with this situation, many scientists abandon any attempt to be broadly informed and, instead, concentrate on being knowledgeable about a highly specialized field. Others make an effort to maintain a wide horizon, and attempting to help fill their needs are such publications as *Scientific American*, *Nature*, and *Science*.

But today other forms of communication compete for attention far more insistently than they did 100 years ago. Radio and television are omnipresent. At any university or other place where research is conducted, a large number of seminars are held. Special symposia and meetings are scheduled somewhere almost every day. Those who would like to communicate by means of the scientific literature, and they are many, should ask themselves, "Is anybody reading?" Today the pressures to communicate are far greater than the motivations for receiving information. The reasons for wishing to publish papers range from the idealistic to the pragmatic. They include the desire to add to human knowledge, to be part of a great international human enterprise, to achieve enduring personal significance, or to build research empires. Additional reasons are the need to publish in order to maintain or advance one's position, and to get grants, some of which provide for summer salaries.

Why do scientists wish to read? The reasons are usually not compelling unless the material is clearly crucial to actions they are contemplating—for example, to experiments they are conducting or planning to conduct. Another reason is that the material might be useful at a later date. In this regard there is general interest in technique papers and in items on instrumentation. Other reasons include the wish to be broadly informed about what is going on in many scientific endeavors, the pleasure of reading, or the enjoyment of seeing how others have solved scientific problems.

In most scientific fields only a small fraction of the workers or even none of them find in a copy of a journal an article crucial to them. I have talked with a number of editors of leading scientific publications in both the physical and biological sciences about their estimate of the degree to which their journals were read. The editors repeatedly stated that they believed their journals were not well read. They cited a gradual trend for members of societies to discontinue receiving the society's journal. They told me that many scientists depend on their colleagues or the grapevine to inform them of any paper that is particularly significant to them. In general, scientists do not feel great incentives to read much. When scanning literature, if a presentation is dull or poor, they move on to something else.

For most scientists in the advanced countries, reading the literature is only one way to become informed. Verbal communication in its many modes is an increasingly strong competitor for the limited amount of time that any scientist can devote to being a receptor. At its best, verbal communication can be much superior to written communication. A speaker can convey facts and much more—sincerity, emotion, and certainty. The receptor can assess almost intuitively the quality of the speaker and the value to be placed on the ideas presented. By tradition, scientists are supposed to be objective and coldly analytical, but that view is nonsense. The best scientists convey enthusiasm and excitement and thus stimulate enhanced creative activity by their fellows.

When two people are both well grounded in a scientific field, interchange between them can be particularly effective. They can quickly brush aside the nonessentials and arrive at the heart of a problem or, if they are discussing a scientific article, can identify the crucial ideas and results in it. Thus, among such experts, the essence of a year's work and the product of a month's labored composition can be transferred in a few minutes. Face-to-face communication is not always feasible, but the telephone serves as a fairly good substitute, and it is increasingly being used.

Verbal communication, however, has its limitations. When conducted within an elite group or invisible colleges, it excludes many others, such as young people and the rest of the world. Verbal communication lacks the permanence of the written word, in that people forget important conversations. In addition, because memories are not always perfect, the further transfer of verbal knowledge is often distorted. Thus, the scientific literature has and will have a continuing important role. But it is clear that the motivations and needs of authors and readers do not coincide, and that in general scientists want and need more urgently to communicate than they want to read.

If the communicators wish to have good reception, they must give thought to methods and mechanisms for conveying messages. The most common failures in written communication arise out of a self-centered blindness that makes it impossible to understand the needs and level of the potential audience, and an inability to compose a lucid article. Because of inability to judge the needs of an audience, authors prepare manuscripts that are full of jargon and readable by only a few peers in the field. Often the article must be read several times to get the drift of the argument—and even then it may be necessary to outline the content to see what is there. The major points of the manuscript are often hidden somewhere in the middle or reserved for an O. Henry conclusion that few readers ever reach. Another major failing is writing too loosely and too long. Often the space given to the development of an idea is disproportionate to its value, or the author goes daisy picking, discussing side issues that are interesting but irrelevant to the main argument. Many of these failings can be and are corrected in the reviewing and editing process that all worthwhile scientific journals employ. But the time and labor involved are substantial.

In spite of an attenuated role in scientific communication and in spite of the costs in time and effort to produce them, the specialized scientific journals continue to have valuable functions. This is especially true of those that achieve prompt publication of manuscripts. In the eyes of research scientists this is an especially important quality and it is often the criterion that determines where a manuscript is sent.

Ultimately, most of the original information appearing in journals is later condensed in review articles and books, but even so the archival character of the journals is essential for preservation of information. Of equal or greater importance is the function that journals perform in keeping the scientific enterprise honest. In private conversations and even in public lectures, scientists often are not rigorous. They tend to be careless about announcing the results of experiments that may not have been well controlled, duplicated, or even performed. However, most of them are much more cautious about what they try to put into print. They fear that other scientists will examine their work and will be zealous in pointing out its defects, both at the time it is being reviewed and later when it appears in print. A scientist who publishes sloppy work can suffer destruction of reputation and, for a scientist, that is very serious. Thus, the scientist who wishes to compile a bibliography is subject to a tough discipline, and it is this discipline more than any other factor that keeps the scientific enterprise relatively honest.

The most important and effective mechanism for attaining good standards of quality in journals is the peer review system. As with any mechanism devised by humans and operated by humans, it is subject to errors and possible abuses. Such failures are often spotlighted by critics, who demand an impossible perfection without knowing how to achieve it in practice. Editors who have experienced the heavy responsibility of dealing with authors, manuscripts, reviewers, and critics are strongly supportive of the peer review system. They assert that some kind of review is essential. They say that if authors knew their manuscripts would be published automatically, many would send in any kind of nonsense. The literature would become worthless, for few people would know what to give credence to. The knowledge that a review system is being employed puts pressure on authors to be careful. But why peer review? Why not an objective, all-knowing, all-wise genius to serve as editor? Such mortals do not exist. It is essential to divide the task of evaluation and to bring expertise to bear on the various papers that are submitted. In many instances, the volume of material and wide scope make it impossible for one person to handle the job. The general experience of many editors is that peer review leads to improvement of nearly every manuscript.

The question "Is valuable scientific material being suppressed?" is often raised. My impression is that, if anything, editors lean over backward to avoid suppression. Conversations with a number of editors indicate that 80 to 85 percent of manuscripts submitted to them are eventually accepted. At *Science* we can publish only about 20 percent of manuscripts submitted to us. We were curious about the fate of rejected material. One way of checking this was to use our terminal to the MEDLINE computer. We found that almost all of our rejected material has appeared in other journals. The principal kind of manuscript that is not eventually accepted is a claim of discovery of perpetual motion.

When scientists and others talk about the proliferation of scientific literature, there is a great tendency to press the "panic button"—to project historical expansion into the future and visualize enormous problems. My guess is that by the time this decade ends, the rate of production of scientific literature will have leveled off.

In the early 1950's, Robert Brode commented on the rapid growth of the number of chemists. With tongue in cheek he calculated that if such growth were to continue, in a few decades all the citizens of the United States would be members of the American Chemical Society. If Dr. Brode were alive today and if he made an extrapolation of current trends in the production of Ph.D. chemists, he would conclude that after several more decades there would be no more chemists. In 1970 the total number of doctorates granted in mathematics, physical sciences, and life sciences per year was about 11,000. Last year the number was 9000. Soon the contingent who are in their most productive years will be declining, and there will be an associated decrease in the production of scientific literature.

Another factor that will contribute to a decline in the production of scientific literature in the physical sciences is the limited availability of expensive new equipment needed for frontier research. Also, there will be a growing tendency for physical scientists to be drawn into applied research, where there is less emphasis on publication.

The electronics revolution is already affecting scientific communication, and its impact is ultimately likely to be profound. The various electronic data bases containing such items as bibliographies, abstracts, and even texts of some articles are making the world's scientific literature far more accessible than it was a decade ago. Large amounts of experimental data are now being stored electronically rather than being printed in journals. With time, the amount of textual material stored will increase. Already, at some installations it is possible to prepare texts of books complete with figures and tables and to store this information electronically. In turn, the content of the book can be transmitted to another location, where it can be viewed on a screen or, if desired, hard copies can be prepared. In principle, the world's scientific literature, including the texts of journals, could be placed in data storage. Whether this will be done—and when—will be largely determined by costs. Who will pay for what?

Another development that is already available to some scientists is electronic mail. This can include the ability to send tables and figures. With the electronics revolution continuing unabated, further impacts on scientific communication are inevitable. How will these affect *Science*? At the moment, the consequences are not clear. However, the continuing vitality of *Science* has stemmed from meeting needs of an important segment of the scientific community. If the policies and content of the magazine evolve with the times and if it continues to meet needs of its readers, it will be around to celebrate a bicentennial.

A view through the plane of our galaxy, looking toward the galactic center, showing the distribution of star clouds and dust in the Milky Way. Viewed this way, our galaxy shows a remarkable resemblance to external galaxies. [*Photo by D. L. Talent taken with the 0.6-meter Schmidt telescope of the Cerro Tololo Inter-American Observatory, Chile; copyright the Association of Universities for Research in Astronomy, Inc.*] →