the number of enrollments in physics rose only from 379,000 to 397,000. In percentage terms, physics enrollment has dropped from 26.4 percent of the total to 22.2 percent. In the same period, enrollment in chemistry rose from 657,000 to 859,000, increasing from 37.6 percent to 38.2 percent of the total.

The reasons for this are not clear, and, as the newsletter says, "the static enrollment in high-school physics is cause for serious concern for physicists and others interested in strengthening science in the United States. Many questions arise. Has physics content merely been displaced from the one-year course to other courses—such as 'physical science' or 'general science'—and in fact is still part of the education of most children? Is the one-year course in physics to be replaced by bits and pieces of physics distributed through the other science courses? Is the level of expected performance in present physics courses too high for the 'average' student? Are college-bound students avoiding physics courses because they think a poor physics grade will reduce their chances for college admission? Are the shortage of competent physics teachers and the uncertainty about course content such that schools are gradually ceasing to make the effort to offer a physics course?"

These questions direct attention to the central problem, that of the assimilation of the new curricula by the behemoth of American public education, with its decentralization, its conservatism, and its formidable difficulties with such practical matters as finance, school size, staffing, and scheduling.

It is also to be noted that the reformers have so far made indifferent progress in carrying the message of the modernized curriculum to the teacher-education institutions.

These qualifications notwithstanding, the results so far show that the triple entente of teachers, researchers, and federal patron have made a most extraordinary contribution to the substance of what is taught in the schools. And major credit must go ultimately to a relatively few scholars who stopped cursing the dark and started lighting candles.

The Information Explosion—Real or Imaginary?

An emerging design for a national system of handling scientific and technical information is described.

John C. Green

In recent months I have heard a number of people speak on such topics as "the information explosion in our times," "the impact of science on our society," and "Is the federal support of scientific research impairing industrial progress?" The speaker usually starts by quoting statistics concerning the federal government's involvement in research and development, which is currently on the order of $15 billion a year. Then he points out that this is 15 percent of the total federal budget, or, expressed another way, over two-thirds of the total national expenditure on research and development by industry, universities, and foundations. The speaker usually proceeds to point out the impact on his pet scheme of these involvements of dollars and personnel. If the economy is lagging it is because we have too many scientists endeavoring to put a man on the moon. If it is difficult to find anything commercially useful in all these research studies it is because we don't have computer storage and retrieval of scientific and technical information. And so it goes.

It seems worthwhile to question some of these premises and conclusions. For example, does the fact that government is allocating billions each year to industry to pursue technical activities in support of government missions have a substantial impact on our economy one way or the other? The federally sponsored efforts are usually separated from the regular work of industry, and the latter doesn't fall off when a company increases its involvement in government contracts for research and development. Moreover, industry continues to carry on research and development of its own to the degree that this proves valuable to it from the standpoint of planning, objectives, and resources. Industry's own expenditures for research and development have more than doubled in the last decade.

My point here is that prudent decisions on the part of management, not federal efforts, control the amount of funds private industry allocates to sales, engineering, diversification, and research and development. To the degree that research and development will increase dividends to stockholders and will promote company growth, it will be supported by management.

The Government Report

Let us look next at the explosion of scientific information, which we are told is caused largely by these massive federal expenditures. It is true that the multiplicity of federal contracts and grants calls for reporting of progress at regular intervals. This is required for three reasons: (i) to keep the contracting agency in touch with work it is supporting; (ii) to make sure that significant findings are recorded and disseminated; and (iii) to identify anything of a patentable nature, so that steps can be taken to protect the con-

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cept. Thus, the preparation of numerous reports in the course of fulfilling a contract is the normal and required procedure. This new type of science record has been cited as a product of the "information explosion" and as grounds for saying that conventional communication mechanisms are obsolete and should be replaced.

It is true that $15 billion of federal funds will be spent this year on research and development. It is also true that tens of thousands of reports will be generated as evidence that something is being done to justify these expenditures. But it should be realized that, in government-supported research and development, the emphasis is on development. Most of these federal dollars are going into the engineering, testing, and evaluating of specific items of hardware—reactors, missiles, and the like. The amount of money spent on uncovering new facts of general application—that is, on research in the conventional sense—is perhaps 10 percent of the R&D budget. It follows that 90 percent of the research reports do not contain much information of interest to anyone outside the research project to which they relate. This emphasis on applications immediately shrinks the information-processing problem in one dimension, since these reports contain less generally useful knowledge than one might expect, and enlarges it in another dimension, since it creates a scientific "needle-in-the-haystack" problem of finding the significant in a large mass of specialized reports.

Where are the pressures coming from for new and dynamic communications mechanisms? They come from a number of sources: (i) from the politicians, whose approach may be that of viewing with alarm and urging bold new ventures; (ii) from people now in the information business, whose approach is ambivalent: the situation exists, it is serious and challenging, but give us the resources and we'll lick it; and (iii) from the "customer"—the scientist and the engineer. While the "customer" is less vocal than the politician or the information specialist, he is dissatisfied, and this fact merits attention.

Unfortunately, there is a multiplicity of customers, and the attitudes of customers A, B, and C are usually quite dissimilar. For example, a working scientist at a university may deny vehemently the existence of the problem. He is in contact with his colleagues here and abroad, significant developments in his field are published in recognized journals which he reads, and he sees the people who are doing useful work at meetings of scientific societies or at frequently held special seminars. On the other hand, an engineer in the materials field may feel overwhelmed by a mass of information on new materials, processes, coatings, and the like if he is without guidance in assessing their merits for his particular problem.

The conventional methods of communicating scientific and engineering facts are creaking a bit; in particular they are not fully responsive to the needs of engineers. What should we do about it? Do we need (as some argue) a huge, government-financed, data-collecting center containing electronic data-processing equipment capable of quickly searching millions of records and printing out a mountain of facts? Or should we (as others contend) give tax dollars to the existing and established services so they can do a better job?

Neither of these schemes is the answer. What we need is a national plan which builds on existing mechanisms and encourages their evolution where changing demands make such evolution necessary. This national plan must recognize the need for new tools where significant gaps exist. (That statement is typical "Washingtonese" in that it sounds reasonable and allows each affected interest to interpret it according to its particular needs.)

What appears to be taking place now is the creation of a sort of interlocking directorate of major information resources. This evolution is one which seems logical because it recognizes and takes into account (i) the character as well as the size of the problem, (ii) the different customers who must be served, and (iii) the existing information resources and their capacity for growth and change.

Before I discuss these existing resources, I have something to say about storage and retrieval by means of machines. It is folly to try to collect, classify, store, and retrieve all the alleged scientific and technical information currently generated. It is theoretically possible to design a center with a computer system for processing the several million studies, reports, papers, and so on, published annually, and to staff this center with thousands of people to read the papers and code them for the computer. However, any attempt to set up such a system would be a colossal mistake—we simply don't know how to code information, or design a computer program, in such a way that the trivial will be weeded out and only the relevant and significant will be retained. If we tried to make such a mass attack on the information problem we would inundate the users of the system with paper, each item of which qualified as relevant to his inquiry. As those who code computer programs say, "garbage in, garbage out." Here we would be producing garbage in very large piles indeed.

What is needed, and what has been missing in most of the information schemes, is the judgment and selection of people skilled in the field in question.

Existing Services

In discussing the existing services I limit my observations to three classes of information resources: (i) The abstracting and indexing services; (ii) the government information projects; and (iii) the specialized centers, such as the Thermophysical Properties Research Center at Purdue University. This does not mean that I ignore or deprecate the other mechanisms of communication—specifically, the scientific journals, the trade press, and the technical library. They are vital and must flourish. However, they are not directly involved in this changing pattern of relationships among the various information services—changes which I believe will produce a strong, realistic information system based on U.S. needs and resources.

Abstracting and indexing services. First, let us consider the abstracting and indexing services. They have served science and engineering well in many ways. Over the years these services, usually associated with a national society, have called upon a cadre of members to screen out the trivial literature and to help in abstracting significant information in terms which are intelligible to their audiences. Those who direct these services have been striving diligently to increase coverage of the world's literature in order to cope with the increase in publication which is taking place in the free world and behind the iron curtain. Let me cite a few statistics. In 1957 the nation's major abstracting and listing services covered about 437,000 titles.

In 1963 the figure was approximately 950,000 titles, more than double the number for 1957. The coverage for 1963 compares favorably with figures for the well-publicized Russian information center, whose 1962 coverage was 752,000 titles. I don't make this comparison to deprecate the Soviet organization; it is a very good one, as I learned when I visited it a few years ago. My point is that we have in existence its full equivalent. We recognize this fact only when we add together the figures for the individual services, most of which are attached to a society, and relate the product of a service to the needs of members of the society to which it is attached.

The abstracting and indexing services are approaching a crisis. They have doubled their coverage and maintained their quality, but they are caught in a "cost squeeze." With twice as much material to report as before, and with costs of printing and distribution rising, they must look for new markets and revenues if they are to survive. Realizing this, the leading services came together in an association known as the National Federation of Science Abstracting and Indexing Services. Here they are probing the question, Can we merge our products and preserve our autonomy? In other words, can combinations of the 21 services which collectively process most of the world's significant literature provide products useful to the problem-oriented engineer or scientist who may need information from two or more fields? (The existing project-oriented services which cut across many disciplines demonstrate the need for this method of organizing information, as contrasted with the single-discipline approach.)

I believe the abstracting and indexing organizations have the imagination and ingenuity to achieve this objective. We must encourage them to do so for several reasons: first, they are recognized and reputable; second, they have years of operating experience; and third and most important, they draw upon the knowledge and aid of U.S. scientists and engineers in extracting useful information from the world's growing mass of science publications.

Government information services. Next we have the government services. The major federal agencies sponsoring research have had to create information services to handle the reports produced in the course of the sponsored research that are relevant to their missions. Four government agencies spend about 95 percent of that $15 billion I mentioned earlier. These are the Department of Defense, the Atomic Energy Commission, the National Aeronautics and Space Administration, and the National Institutes of Health. The control and communication problems relative to their many projects have caused the first three to set up large information-processing programs. The fourth, the National Institutes of Health, is engaged in designing a sizable program covering information-handling within its sphere of interest.

These agencies have also come together at the management level. At the instigation of Jerome Wiesner, during his tenure as Science Adviser to the President, a Committee on Scientific Information was created, representing all government agencies with major information-processing programs. The committee is looking at the individual programs of the agencies, hoping to increase efficiency and reduce overlaps. The next step should be to see how the government services can best fit into a national pattern. Transfer to the scientific societies, and to the new family of specialized centers, of part of the responsibility for evaluating government reports and communicating their contents would seem to be a simple, logical, and effective next move.

I have stressed the problem faced by the engineer who tries to keep abreast of research findings. He finds it particularly hard to locate critically evaluated data on the physical and chemical properties of materials. To provide readier access to such reference data, the Committee on Scientific Information has established a National Standard Reference Data System under the leadership of the National Bureau of Standards. The idea is to enlist the talents and resources of a number of data centers operated by universities, research institutes, and other nongovernmental organizations. Each component of the system will be required to meet specified standards and to produce processed data which are compatible with data produced by the other centers in the system.

Specialized centers. This brings me to the third group of information resources, the specialized information centers, of which the Defense Materials Center at Battelle Memorial Institute and the Thermophysical Properties Research Center at Purdue are excellent examples. The creation and growth of this type of service in the last few years have been remarkable. Most of these centers have received considerable fiscal support from the Department of Defense and have therefore emphasized areas of science of special importance to a Defense mission. The unique and significant functions of a specialized information center are critical analysis of the information processed and distribution of the selected information in a coordinated, internally consistent, and authoritative form. Of course, the greater speed of communication, as compared with that attained through conventional publication, is also important.

These functions distinguish such an organization from a library or documentation center. If, with the passage of time, they are neglected, the center will lose its effectiveness and its excuse for existing. This is a very real danger.

Summary

What have I been trying to convey? Essentially, that we are engaged, more or less consciously, in designing a national scientific and technical information system. In the design and construction we build on what we have, molding it, where necessary, to the needs of the "customers." It is the American user of information with whom we are concerned. A large, monolithic center may serve the needs of the Russian scientist and engineer, because his culture, his economy, and his resources are Moscow-oriented. Precisely the opposite kind of system will best serve the needs of the U.S. scientist and engineer, because our culture, our economy, and our resources are decentralized and diverse.