"Science Citation Index"—A New Dimension in Indexing

This unique approach underlies versatile bibliographic systems for communicating and evaluating information.

Eugene Garfield

Over a quarter of a century ago H. G. Wells made a magnificent, if premature, plea for the establishment of a world information center, "the World Brain" (*1*). To Wells, the World Brain became the symbol of international intellectual cooperation in a world at peace. The realization, within our lifetime, of the physical and intellectual achievement envisioned in *World Brain* no longer lies in the realm of science fiction. The ultimate specification for a World Brain must await more fundamental studies and understanding of information science. However, the increasing convergence of such previously unrelated fields as genetics, linguistics, psychology, and chemistry foretells exciting realignments in classical conceptions of the "information" problem. Unquestionably there are many different forms and arrangements which a World Brain could assume. Vannevar Bush's "Memex" was a microfilm version of the universal fingertip library (*2*); Memex stimulated considerable speculation but also produced some realistic work (*3*). Tukey's "Information Ledger" is a recent specification of the desiderata for a universal information system (*4*). More recently, Senders has given an approximate quantitative measure of the information content of the world's libraries (*5*). Surely the increasing awareness of the science-information problem on the part of both the legislative (*6*) and executive (*7*) branches of government will add momentum to the inevitable trend toward establishment of a world information center.

The main purpose of this article is to provide some perspective on the science-information, or science-"indexing," problem; to review briefly the developments in citation indexing that have occurred over the past 10 years; and to indicate why the recently published *Science Citation Index* (*8*) is a harbinger of things to come—a forerunner of the World Brain.

The average scientist thinks a World Brain would be extremely useful. The possibility of having all recorded knowledge at one's fingertips is fascinating. The librarian, however, eminently more practical on this topic than the scientist, because he has learned to live with bibliographical poverty in the midst of scientific wealth, thinks of the enormously detailed problems of bibliographic control (*9*). Therefore, the librarian may be the one who best appreciates the implications of the *Science Citation Index* for bibliographic control. It is the first really serious attempt at universal bibliographical control of science literature since the turn of the century (*10*). On the other hand, the librarian is sometimes too acutely aware of the detailed problems involved in compiling an international inventory of science—precisely what the *Science Citation Index* is. I believe the need for such an inventory, for such bibliographic control, is indisputable (*11*).

Whether or not citation indexes are useful is a question that has now been answered. We have enough favorable experience in using them to know they are desirable and useful. However, a citation index must meet the same economic test that all products in our society must meet: Does the cost justify the benefits? To measure its value to the scientific community is not simple. Do the cost and difficulties of retrieving pertinent literature justify bypassing the literature and chancing a replication of research? Or, as Maddox recently phrased the problem: "Is the literature worth keeping?" (*12*). The Weinberg Committee (*7*) maintains that the literature is an integral part of the research process. Printed communication still has a long life expectancy as a means of imparting current information and retrieving data; it will be with us at least until we have developed science communication to the point where all indexes, journals, books, and other printed media become obsolete and a World Brain takes over. Meanwhile, the initial bibliographic control necessary for establishing a World Brain is economically justified by the immediate and interim requirements of the expanding complex of science and technology.

If we ever achieve "total communication," a state of research nirvana, then an enormous time-shared, random-access computer memory will augment man's finite memory and replace printed indexes and catalogs. In this condition of nirvana a World Brain will itself have become an auxiliary to man's own brain. Or, as Bernal has stated it (*13*), "The speculations of the future may then be the speculations, not of one man or of many men, but of all humanity and their machines." But this achievement will require a far greater commitment to the task of accumulating and communicating scientific information than we have ever been willing to make previously. In any event, the direct linking of conceptual information which is made possible for the first time through citation indexing will be a vital part of such total communication.

An Example

In June 1955 a paper appeared in *Science* entitled "Citation indexes for science" (*14*); it was in part based on suggestions made by Adair (*15*) and Hart (*16*). In 1957 there followed a paper on the applicability of the citator system to patents (*17*), which cited Hart (*16*) and Seidel (*18*) in support of arguments for establishing a citation index to patents. In two subsequent papers (*19, 20*) the a priori nature of conventional indexes was discussed in contrast to the a posteriori character of citation indexing. The relationship of the citation index to the problem of achieving a Unified Science Index was explored at the International Conference on Scientific Information in

The author is director of the Institute for Scientific Information, Philadelphia, and lecturer in information retrieval at the University of Pennsylvania.

1958 (*21*). Fano (*22*), Ernst (*23*), Tukey (*24*), Savage (*25*), Lipetz (*26*), Kessler (*27, 28*), Atherton (*29*), and Salton (*30*) have also pursued various ramifications and possibilities of citation indexing.

The foregoing bibliographic recapitulation is intended to emphasize, to the reader unfamiliar with citation indexes, both the advantages and the simplicity of citation indexing. The 17 papers cited in the preceding paragraph are associated here in this article. A citation index would automatically lead the user to this group of related works, provided he knew of any one of the cited references. With a citation index, this article and the paragraph in question would be retrieved regardless of the date or the journals in which the cited papers originally appeared. The scatter of the 17 references, however, also illustrates some of the complexities of compiling citation indexes. The preceding paragraph is a historical-bibliographic introduction comparable to that provided by many authors in writing scientific papers.

Consider the reader who has never heard the term *citation index* but wants information on this topic. His difficulties in finding the article you are now reading will illustrate the difficulties of finding information by conventional methods. It would be almost impossible for one unfamiliar with the citation-index concept to search for papers under the heading "citation indexing" because the term probably would not occur to him. If the idea of citation indexing did occur to him, the descriptive terminology that he selected in searching for the citation-index "idea" would probably have been different. And yet, previous knowledge of any one of the references cited in this article, or cited in any of the other 17 "citation-index papers," would, through the use of citation indexes, bring to the attention of the requester this "new" concept. Even in this circuitous example there is no paradox involved in calling the results of the search a "new" concept, since the actual search could have been performed by some other person using a citation index, while the requester himself remained unaware of its existence. Thus, interest in Vannevar Bush's paper (*2*), Avakian's work (*3*), or any other of the 17 cited references which is relevant to, but does not specifically name, citation indexing would open the door to the idea of citation indexing.

Consider the class of readers who might have thought about the "idea" of a citation index prior to publication of this article. They fall into two subclasses—those who might have called it a citation index or something roughly equivalent, such as a "reference index" or "citator," and those who might not. The latter subclass includes Fano (*22*) and Ernst (*23*), whose linguistic conception of the citation-index "idea" was quite different from mine, though the end result was essentially the same. The semantic difference lies in my thinking of a citation index primarily as a printed index, whereas they visualized a "machine" index. This manipulative difference in no way alters the basic commonality of the two systems. The information processed in the two is exactly the same—citations appearing in bibliographies.

To continue our example—the literature searcher interested in finding published articles on "the citation index" by conventional methods faces a basically difficult task. Even though he may have the terminology correct, or nearly correct, he will find that *Science* is one of those journals that is *selectively* indexed by the leading discipline-oriented indexing services. "Chemical" articles are indexed by *Chemical Abstracts*, "physical" articles by *Science Abstracts*, "biological" articles by *Biological Abstracts*, and so on. But even if one assumes that the conventional indexing services do abstract articles such as this, an additional degree of uncertainty is then introduced by the possibility (and too often the probability) that either the indexer or the searcher did not use the "correct" terminology. Concepts or ideas are extremely difficult to handle consistently in classical subject indexes.

For the other papers in the list of 17 citations, effective selection and indexing treatment by the conventional indexing and abstracting services is even more unlikely than it is for the cited article from *Science* (*14*). The article in the *Journal of the Patent Office Society* (*17*) illustrates one of the many serious deficiencies of our fragmented, discipline-oriented indexing activities (*31*). That paper, on indexing chemical patents, was published in a legal journal, and thus the audience of librarians and chemists who might be interested in the paper was sacrificed for an audience of patent attorneys. The situation is even worse with respect to references *20* and *21*, both of which are part of the published proceedings of a conference. Hanson and Jones have shown that most papers appearing in the published proceedings of conferences are never indexed (*32*). Since the number of published conference proceedings is quite large, a considerable amount of important literature would be buried if the participants in these conferences did not cite the same papers in subsequent articles, published in journals which *are* covered by indexing and abstracting services. This is reflected in studies by Touloukian *et al.* (*33*) which show that it is more efficient to use an indexing service to locate a few recent papers and then search bibliographies in these papers than it is to search the indexes exclusively.

The conventional discipline-oriented indexes thus leave much to be desired with respect to breadth of coverage and as means of indexing consistently and by concept. If, instead of searching for papers on the subject of citation indexes, the reader seeks papers on any one of dozens of interdisciplinary subjects investigated today, without knowing the exact headings under which they are indexed, he encounters similar difficulties. This will be apparent if, for example, he tries to compile rapidly a bibliography on one of the following topics: theories on the origin of life; nucleic acid staining techniques; applications of computers to biomedical research.

What Is a Citation Index?

A citation index is an ordered list of cited articles each of which is accompanied by a list of citing articles. The citing article is identified by a source citation, the cited article by a reference citation. The index is arranged by reference citations. Any source citation may subsequently become a reference citation. At the time of indexing, the article you are now reading would be considered a source. In that case it would appear in the citation index under all the reference citations in "References and notes" at the end of the article. It would also appear in the source index which accompanies the citation index proper.

The description of a citation index does not imply a particular order for the list of cited references. We have studied in great detail the many ways one can arrange a citation index. These include arrangement by author, journal, year, document serial number, volume, page, or other parameter. Any

fragment of the usual citation might be the basis for organizing a citation index. The decision to arrange the *Science Citation Index* (*8*) by author was based on a total-systems study in which it was determined that the typical user requirement is to find what sources have cited a particular reference, albeit at times the reference citation is incompletely recollected. Our studies have also shown the desirability of providing, with the citation index, a complete source index containing full source-article titles and certain additional data. This source index is similar to an upgraded conventional author index covering all disciplines—the first objective of the Unified Science Index (*21*). Arrangement by author is favored in the citation index and the source index because the research scientist usually approaches the literature first by author.

By using a citation index one determines what *subsequent* papers have cited a particular reference. How would the new citation index help you find articles on the subject "citation index"? I have already shown why it would be difficult to find these with conventional subject indexes. Suppose you have found, by chance, the article by Adair (*15*) by scanning back volumes of *American Documentation*—a not unlikely supposition for someone interested in finding such information. When you have located the Adair article by such browsing you look it up in a cumulated citation index for the source years 1955–64; the index immediately tells you that at least seven papers have appeared on the subject *since* 1955 —*14*, *17*, *19*, *21*, *24*, *26*, and the article you are now reading—all citing Adair's paper! However, this is only the beginning. By a technique called "cycling" you can quickly find the other papers on the subject of citation indexes, as well as others related to the use of citations. "Cycling" means examining the bibliographies of the papers you start with, and of the source papers obtained, in order to locate additional relevant works. By looking up the latter in the citation index you find new citing sources.

For example, in my paper in the *Chemical Bulletin* (*19*) the letter by Schoenbach, in which he criticizes citation indexing, is cited (*34*). Schoenbach's paper in turn refers to my original paper (*14*), which, through the citation index, leads to my reply (*35*). Furthermore, by successively checking on whether the "source" articles which cited Adair have themselves appeared later as cited references and following up any secondary sources so located, one quickly generates a complete bibliography.

As the literature of a field increases, the redundancy in bibliographies makes it easier to up-date the search, no matter which of various related articles is located first. This redundancy also reduces loss of information in the citation index through typographical or other errors, including the omission, unwitting or otherwise, of relevant references by authors.

How can we assume that a searcher will find any of the necessary articles to begin his search? The user of the citation index must have a starting point. Here is a major difference between conventional subject indexes and citation indexes.

Proponents of conventional language-oriented subject indexes implicitly assume that the typical reader does not know of any papers on the subject he is investigating. How often is this true of the working scientist? More often, perhaps, it is a librarian or student who seeks information without prior knowledge of the subject. If the user does not know of a previous work on the subject he must find one through a book, an encyclopedia, or a colleague. These can usually supply one or more starting references. If there is little or nothing written on the subject the user will have a difficult time no matter what he does, as no literature search can turn up what doesn't exist!

Too Many Citations or Too Few?

Although the average published paper is cited less than once each year, certain papers are very frequently cited. To take an extreme case, the paper most frequently cited in 1961 was cited over 500 times (*36*). While, by most search standards, this makes a long list of citing papers to scan, even this number is not one bit excessive for the chemist, sociologist, or historian interested in writing a complete review or evaluation of the method cited. Moreover, several of the citing papers introduced procedural modifications.

It is frequently assumed that the usual citation practices lead to an impractical number of sources for a particular reference. In rare instances this may be true, but, as we have seen, for certain purposes the searcher may be only too glad to have a rich and comprehensive bibliography to scan. Experience shows, however, that the number of sources uncovered is in most cases quite manageable. Furthermore, the yield of sources can be reduced by various simple means whenever this is required. One such method involves the use of "bibliographic coupling" (*28*).

In designing the *Science Citation Index* (*8*) it was assumed that the user could specify one or more references as starting points. It may sometimes be necessary or desirable to start with more than one reference. In these cases the searcher can cull the sources by looking up in the index only those sources which cite two or more of the starting references. This is the essence of bibliographic coupling. Or sources may be selected or rejected on the basis of authorship, journal title, article title, number of references, "type" of article, date of publication, and classification numbers.

The refining of a search result by these methods is generally quite unnecessary. In an annual cumulation comprising 1.4 million references (*37*), the average number of citing sources per reference cited was found to be about 1.5. It is easy to lose sight of the fact that, contrary to the general cliché that there is too much scientific information, there is often little or no information available on a specific point (*38*). The number of references cited each year is a function of the size of the current and past literature and of the writing habits of the authors. However, it is interesting to note that the average number of citing sources per reference cited did not change appreciably once we exceeded a critical level of several hundred key journals.

In day-to-day research, the citation index will also provide the scientist with useful leads toward an *unspecified* information objective. Frequently the scientist-user of indexes does not have a precise objective in mind. He is simply exploring information pathways that appear to be exciting and interesting. The citation index facilitates this browsing process. On the other hand, the competitive nature of modern research (*39*) often involves him in negative literature research. Many persons legitimately hope they will *not* find pertinent references—as, for example, in patent searches. In evaluating the citation index and other indexes one must consider the ease with which one can obtain a negative result with a high degree of certainty.

Obviously citation indexes will be effective only to the extent that the bibliographies in published papers are accurate reflections of the earlier literature. In evaluating papers submitted to journals, referees should determine whether all pertinent references have been provided. The citation index will significantly assist the referee in identifying such pertinent references. A paper recently reported as novel a method of analyzing for peptides (*40*), even though the same work had been reported 4 years earlier (*41*). There is no question that, had the authors or referees had access to a citation index, the second paper would not have been published, and the subsequent correction (*42*) would have been unnecessary. The two papers (*40, 41*) contained four references in common; from any one of these the earlier work could have been pinpointed through the citation index. Our files contain numerous examples of this type.

How serious is the problem of noncitation of pertinent references, for whatever reason, by authors? Most of us have seen examples of what appears to be an obvious omission of a reference to a related piece of work by another author. Such omissions will undoubtedly affect the utility of the citation index for "current awareness" searches. How much cannot yet be determined. The fact that papers which do not cite the earlier literature will not be retrieved directly through citation indexing may exert some influence on authors in the future. However, most papers do contain pertinent bibliographies, and, in time, most papers are cited a few times. It is a rare paper which neither cites nor is cited. However, editors and referees, in accepting or recommending acceptance of a paper, might insist that certain standards of literature search be met by the author, just as similar standards are assumed by anyone applying for a patent. References in patents, however, are supplied by the referee (examiner), not the author (inventor).

Dissemination Problem

I have discussed some of the ways in which the citation index can be used to search literature. If a printed list of sources which cite a particular reference is of use, then a service, through which such citations, or the articles themselves, are automatically and selectively disseminated, will also be useful. It is easier to decide how relevant a citing paper is by quickly scanning the paper itself than by reading a title or an abstract. Through such scanning the starting reference can be considered in context within the source article. This step is aided by the fact that most citations are enumerated and easily traced within the body of the text. A sentence or paragraph thus disclosed may contain vital information which had been completely ignored by an abstractor or subject indexer. The design of just such an automatic weekly alerting service has been completed, and indications are that it will significantly aid the individual in keeping abreast of his specific interests, as defined by his pertinent "question" citations.

Extensions into Subject Indexing

What are the possibilities of using the citation index in conjunction with conventional indexing? In discussions of citation indexes at the Dorking Conference (*20*) it was correctly concluded that each reference citation is a form of index "heading" or descriptor. A similar conclusion was implied in the statement that each author "indexes" his own papers each time he cites another paper (*14*). Now, let us assume that the ideas expressed in a particular source article are reflected in the index headings used by some conventional indexing system. In that case, a display of the descriptors or subject headings assigned to that paper by the indexer constitutes a restatement of the subject matter of that paper in the indexer's terminology. When the indexing is automatic and based on article titles, then the key words restate the title and presumably restate the main subjects of the paper. Suppose you now collect and examine the array of descriptors generated by all the references cited in a particular source paper. How accurately will this list of descriptors describe the contents of the source document? Some preliminary experiments have revealed that the terms selected in indexing a source paper corresponded closely with those used to index the reference citations. The combined array of descriptors for all cited articles characterized the subject matter of the source article in great detail. There are certain exceptions; for example, the nomenclature used to index a previously incompletely described drug is inadequate for the subsequently completely identified chemical structure.

The implications and ramifications of these experiments may prove valuable both in future conventional cerebral indexing and in computer indexing. First, the speed and consistency of conventional indexing would be increased if one could quickly display (by means of computer methods) the earlier indexing terms assigned to the references in a particular source article being indexed. This idea was implicit in the Philco Medlars proposal (*43*), in which it was suggested that the indexer would be capable of direct communication (online) with the computer. It was also implied in Fano's "matrix," in which the degree of relevance of two documents is determined by comparing the lists of reference citations. In Fano's system, two documents would be considered "identical" if the lists of bibliographical citations were identical. This is a specific case of the more general axiom that two documents are indistinguishable within any retrieval system if all of the assigned descriptors are the same (*44*). The only way the documents can be differentiated is by the assignment of additional descriptors—that is, by indexing in greater depth.

Machine Citation Index

If the same magnetic-tape files that are used to prepare the nonmanipulative printed citation index were searched by computer, papers could be associated through machine examination of the descriptor patterns of cited papers. In this way one could incorporate and utilize existing indexing of earlier papers in mechanically evaluating the relevance of source papers.

The machine citation index would also facilitate studies on why certain papers are never cited. Kessler reports the existence of a large number of such papers (*27*). What does this signify? Many factors can contribute to a lack of citations. In addition to the obvious possibility that a paper is relatively worthless, several information concepts come into play. For example, information may remain untransmitted if an article has been published in a relatively obscure journal, in a journal generally devoted to articles in a very different field, or in a language or jargon foreign to potential users. The article may be dry or very long, and thus not widely

read. A poorly selected title or bibliography, or both, can also lessen citation of an article. However there is another, and challenging, factor: the timing of a scientific article can be out of step with the general development of science —out of phase with the general communication network. The "time lag" can be positive or negative, depending upon the quality or originality of the message. "Like mutant genes, an idea may be before its time—that is, the social climate may not be right for its acceptance" (*45*).

A paper may be so far ahead of its time that it is not appreciated or cited for many years. Mendel's experiments with peas in his monastery garden, Fleming's observations of bacterial lysis in mold-contaminated petri dishes, Pressey's reports of "An Apparatus which . . . teaches" all lay buried in dusty tomes for decades before their vast significance for genetics, antimicrobial therapy, and teaching machines became widely recognized. Indeed, the history of science abounds with examples indicating that the scientific community is incapable of quickly absorbing radically new ideas or information. If we assume that the papers which have never been cited include those which were ahead of their time, the citation index may afford a means of ferreting out those papers which might deserve reevaluation, redissemination, or even republication. One experiment contemplated at the Institute for Scientific Information is the identification of genetics papers which were not cited in the *Genetics Citation Index* (*46*). These would be reappraised by experts with respect to possible "revival" value. It would be gratifying to uncover some hitherto uncited papers buried in the literature which, in the light of more recent scientific discoveries, do deserve republication.

Citation Indexes and Abstracting Services

Recently Bennett (*47*) has reiterated my earlier recommendation that an index to the abstracts in specialty journals and to abstracts prepared by the smaller abstracting services be compiled (*21*). Frequently these are abstracts which include criticism. As such, they constitute original publications. Every author should know of such critical abstracts of his papers. In literature searches, abstracts may serve in lieu of the original articles, particularly when the original article is in a foreign language, or when it is not readily available. Citation indexes can be used to locate these abstracts quickly and to identify unabstracted articles (*31*).

Author Citation Index

A random-access computer memory does not require special ordering for data storage. In such memories the arbitrarily assigned data-addresses need not be known to the user. By contrast, a printed citation index must have a logical order. An alphabetical arrangement of reference citations by cited author has definite advantages and disadvantages. One advantage is that an author arrangement brings into proximity references to different works by the same author. In any other arrangement, citations to the work of a single author would be scattered. A further advantage is that the user who remembers no more than the author's name and the approximate year a paper was published can still usually complete his search. With the author arrangement there is a small but distinct complication: the name of a cited author may appear with different spellings in different journals. This problem is aggravated by the fact that the scientific literature employs many languages, alphabets, and transliterating systems. For instance, when names are transliterated from English into Russian and then back into English, the original spelling may be lost. An American named Wheeler may come through this mill as Viiler. Hilbert comes through as Gilbert. Chinese names present even more bizarre examples. To make things worse, the *Journal of the Chemical Society*, and others, drop authors' initials in citations (*48*). A Reference to Smith, *Proc. Chem. Soc.* **1953,** 1234, is adequate for most purposes. However, specific identification of the author is made difficult by this practice. Fortunately, only a small percentage of citations present such problems, but these do increase the cost of processing and the difficulties for the user. One solution may ultimately be to prepare brief "contents pages," which contain, for every journal ever published, standardized spelling of the authors' names. The computer can then be used to replace incomplete, incorrect, or variant spellings with this standardized form. The preparation of "contents pages" is also a requisite for the mechanical identification of articles which have never been cited, discussed earlier.

In compiling the *Science Citation Index*, an interim solution to the problem of orthography has been to have the computer use less than the author's full name when first identifying two or more references to the same citation, then to have the computer select one variation of the cited name for use in the index.

Another complication of the author citation index is the problem of multiple authorship. If one expects to find citations to all the work of a given author, then that author must appear as the primary author in the citations, or the index must contain cross references or duplicated entries for all co-authors' names. The average number of authors per paper now exceeds two (*49*). To list all co-authors in a printed author-citation index would approximately double its size. One partial solution to this cost and space problem has been the compilation of a separate bibliography or index of source articles, with all junior and senior authors listed. Preparation of a cumulated cross-referenced file based on this source index will eventually allow the user to quickly identify all the works to which a given author contributed.

Conclusion

The availability of comprehensive citation indexes now opens new roads to the solution of numerous scientific and documentation problems. Citation indexing bypasses some of the limitations of classical subject indexing, and its techniques can be incorporated in the existing communication system as well as in the World Brain, whatever shape or form that may take. Production of citation indexes has become an eminently practicable procedure, and the results of research on over 2 million citations lead to the conclusion that we cannot afford to neglect this unique and versatile instrument, in view of the accelerating tempo of modern interdisciplinary scientific research. The main objective for the immediate future is to increase the coverage, in terms of chronology and number of source publications, so that we will have a relatively complete inventory of all scientific and related research. To do this will require the support of the entire scientific community.

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