

# Citation Indexes for Retrieval and Research Evaluation

presented by

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at

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**Capri**

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As Dr. Salvatore and Susan Cozzens are aware, when I was first approached to give this talk, the original manuscript for this talk had been submitted for publication over one year ago and is now being evaluated at *Nature*. Its primary purpose was to provide a synoptic history of citation indexes for information retrieval, information dissemination, and writing the history of contemporary science. In that context scientometrics and bibliometrics are treated simply as a by-product of *Science Citation Index*® production.

As you know, there is now a substantial industry involving citation studies. Many of them, for your purposes, are somewhat irrelevant, e.g., those involving the selection and deselection of journals by research libraries, journal evaluation and ranking by editors and publishers, or tracing the lifetime impact of individual scholars. My presentation today essentially avoids discussion of research evaluation methods, per se. This may seem strange to you but such methodologies for research evaluation will be dealt with extensively by others at this conference.

However, at the outset I will refer to validating studies of citation analysis. This was epitomized by the recent huge report published by the National Academy of Sciences titled *Research Doctorate Programs in the United States - Continuity and Change*.<sup>1</sup> Using an extensive questionnaire technique addressed to most academic research institutions in the USA, the tabulated results were correlated with citation and publication analyses and concluded that:

"The clearest relationship between ratings of the 'scholarly quality of program faculty' and these productivity measures occurred with respect to 'citation' - with faculty in top-rated programs cited much more often than faculty in lower-rated programs who published."

Questionnaire surveys are but one of many different subjective approaches to research evaluation.

Cornelius Le Pair has stated succinctly the approach to citation analysis that I have always supported: "Citation Analysis is a fair evaluation tool for those scientific sub-fields where publication in the serial literature is the main vehicle of communication."<sup>2</sup>

It's important to recognize the ambiguity of the term "Research Evaluation." Sometimes it refers to faculty evaluation, other times graduate research programs. Others, like granting agencies, are doing research evaluation of particular areas of science. In all these studies methodologies for the proper identification of specialties and sub-specialties (invisible colleges) is crucial. The work of Henry Small, Callon, Van Raan, and others on co-citation and co-word clustering is important to note. Any citation analysis for research evaluation must take advantage of such methods to provide an informed decision for funding or award purposes.

The idea of a citation index for science was the culmination of my investigation of the linguistic and indexing characteristics of scientific review articles and a serendipitous encounter with *Shepard's Citations*. Both these inspirations resulted from interaction with established scholars. My initial interest, which soon became a preoccupation, was aroused by pharmacologist/historian Chauncey D. Leake.<sup>3,4</sup> My introduction to the U.S. legal citation system came from a retired vice president of *Shepard's Citation*, W. C. Adair,<sup>5</sup> who wrote to me about in March 1953, towards the close of the Johns Hopkins Welch Medical Indexing Project, of which I was a member.

When the Project closed in June, I enrolled in the Columbia University School of Library Service. There, early in 1954, I wrote a term paper proposing the creation of citation indexes. After much revision and help from Johns Hopkins biologist Bentley Glass, it was published in *Science*<sup>6</sup> in 1955. Its primary aim was to improve the retrieval of science information. That the putative *Science Citation Index*<sup>®</sup> (*SCI*<sup>®</sup>) should be unified, that is multi-disciplinary, and each journal indexed cover-to-cover was further reiterated in a paper I presented at the 1958 International Conference on Scientific Information.<sup>7</sup>

At that time, there was widespread dissatisfaction with the array of traditional discipline-oriented indexing and abstracting services. They were all inordinately late. Indexing was inconsistent and uncoordinated. Selection policies left major gaps in coverage.

### **The Impact Factor**

Only a few lines of my 1955 *Science* paper referred to the "impact factor" of individual research papers. The idea of average citation frequencies, that is, journal impact factors, now so widely used for evaluation analyses, did not develop for more than a decade.<sup>8, 9</sup> Ironically, in view of my stated objective, these impact measures have received much greater attention in the literature than the proposed use of citation indexes to retrieve information. This is undoubtedly due to the frequent use and misuse of citations for the evaluation of individual research performance -- a field which suffers from inadequate tools for objective assessment. While there are countless legitimate applications of citation data, in the hands of uninformed users, unfortunately, there is the definite potential for abuse.

It is safe to say that journal impact factors, as reported each year since 1979 in the *SCI* and *Social Sciences Citation Index*<sup>®</sup> (*SSCI*<sup>®</sup>) *Journal Citation Reports*<sup>®</sup> have been the most widely used derivative metric of citation analysis. They are extensively used by libraries for journal selection and weeding and by faculty selection committees as part of the evaluation of individual performance.

### **Validating Studies of Citation Analysis**

There is a huge literature on citation analysis. But there are only a few studies that could be called "validating," that confirm its value in literature searching or evaluation research. This lack of extensive validating studies has not affected its pragmatic utilization for these purposes. The work of Julie Virgo in 1977<sup>10</sup> demonstrated a high correlation between citation analysis and peer judgment in identifying research-front leaders in cancer.

"The purpose of this study was to develop, using objective criteria, a statistical procedure to evaluate the importance of scientific journal articles. Two approaches were taken using articles from the field of medicine.

"The first tested the specific hypothesis that journal articles rated important by subject experts would be cited more frequently in the journal literature than would articles judged to be less important. The hypothesis was tested by determining the extent to which a measure based on citation frequency could predict the subject experts' opinion on the importance of papers presented to them in pairs (one pair member was an infrequently cited paper and the other a frequently cited paper). The experiment showed that citation frequency was able to consistently predict the more important paper.

"To determine which other factors were associated with articles judged important, a stepwise regression analysis was made. Although ten variables were considered, only two were significantly related to the differences between articles that had been rated on a scale of one to five of importance. While citation frequency had been a strong predictor of pair-wise judgments about the importance of articles, the regression equation performed even better in agreeing with judges' ratings.

"The design of this study called for judgments to be made on pairs of articles, one pair member being an infrequently cited paper and the other a frequently cited paper, since using extremes maximized the chance of detecting small effects.

"It is suggested that a potentially fruitful area for further research would be to obtain judge ratings on sets of articles coming from a variety of citation frequencies, not just extremes. Using the regression equation obtained in the present study, importance predictions about each of the articles could be made and compared with the subject experts' opinions about the articles. In addition, similar studies in other areas of science should be carried out to determine the applicability of the approach used in the present study, to subject areas other than that of medicine."

The same year, Henry Small performed a similar study for the field of collagen research.<sup>11</sup> Through a longitudinal study of co-citation linkages, he identified the most important advances in collagen research over a five-year period. The results were validated by questionnaires. The survey "demonstrated that the clustered, highly-cited documents were significant in the eyes of the specialists, and that the authors of these papers were, by and large, the leading researchers identified as such by their peers."

In 1983 Michael Koenig published bibliometric analyses of pharmaceutical research.<sup>12, 13</sup> The second of this series involved a comparison between bibliometric indicators of expert opinions in assessing the research performance of 19 pharmaceutical companies. He concluded inter alia that expert judgments were very predictable from the bibliometric measures, while the converse relationships were not.

But much larger validation studies based on large populations across most academic disciplines had already been conducted earlier by the sociologist Warren Hagstrom.<sup>14</sup> In his paper he used

citation counts from the 1966 *Science Citation Index* which was just two years after the service was launched. Publications and citations were determined to be the two leading determinants in an analysis of department quality indicators in 125 university departments.

These researchers compared the results found through questionnaire surveys of U.S. faculties with the results of citation analyses. And several subsequent NRC studies have combined publication productivity and citation data with peer surveys including the most recent highly publicized NAS report.<sup>1</sup>

During the past two decades, dozens of papers have been published that use bibliometric data to identify leaders in various specialties by measuring article productivity, citation impact, and most-cited papers. When used in combination with peer judgments, the overall validity of these studies is rarely questioned. The most recent example is the work of Nicolini et al.<sup>15</sup>

Nicolini describes an evaluation of 76 candidates for university chairs in biophysics and related disciplines. He correctly points out that the evaluation of a person by scientometric methods is complex and needs more precautions than bibliometric analyses on countries, institutions, or groups. Since this work is so recent and known to so many present, I will not repeat his conclusion (p. 106) about the relevance of such studies provided the proper normalization procedures are followed.

Comparative validation studies in information retrieval have also been limited.<sup>16, 17</sup> Apart from retrieval and research evaluation, there have been hundreds of applications of citation data in studies designed to test various hypotheses or conjectures or to identify key people, papers, journals, and institutions in various scientific and scholarly specialties. Not surprisingly, fields like economics and psychology, where quantitative measures of human behavior are the norm, have produced a large fraction of such studies. Various correction factors have been devised to improve identified discrepancies between quantitative citation studies and human peer judgments. The need to account for age and other differences was predicted by Normal Kaplan,<sup>18</sup> Margolis,<sup>19</sup> and others.

### **Information Retrieval**

At its official launch in 1964, and for another decade,<sup>20,21</sup> the utility of the *Science Citation Index* as a retrieval and dissemination device was hotly debated in library circles, but it is rarely questioned today. We do not know the precise extent of its current use for information retrieval. But we do know that it is frequently used in most major research libraries of the world, in print, CDs, or online. Nevertheless, it is a sobering commentary on the conservative nature of education in science, medicine, and the humanities that only a fraction of scientists, physicians, or scholars ever receive formal instruction in the use of citation indexes. With rare exceptions, researchers do not encounter *SCI*, or *SSCI*,<sup>®</sup> or *Arts and Humanities Citation Index*<sup>®</sup> (*AH&CI*<sup>®</sup>) until they enter graduate school. A few liberal arts institutions have incorporated such training into undergraduate instruction, but the work of Evan Farber at Earlham College is the exception rather than the rule.<sup>22</sup> At some large research universities, such as Purdue or Michigan State University, where chemical literature searching has been taught for some time, use of *SCI* is covered routinely, especially as a means of augmenting searches begun with other indexing services.

**FIGURE 1: HOW TO DO A SEARCH -- HAROLD UREY EXAMPLE**

**HOW TO DO A SEARCH**

Starting point for most searches in the **SCI** is a specific work. □ For example: suppose you are interested in the subject of Urey's article: "Lifelike Forms in Meteorites."

### Lifelike Forms in Meteorites

Are fossils present in carbonaceous meteorites? The evidence is suggestive but as yet inconclusive.

Harold C. Urey

At a meeting held 1 May 1962 at the New York Academy of Sciences, a group of speakers was presented dealing with the 1700 particles per milligram claimed by the Fordham group, never in contradiction to reports

mentioning my early skepticism in regard to the whole matter and my suggestion that additional experiment hydrocarbons extracted from meteorites be made by spectroscopic methods, to supplement the mass spectrographic analyses. In New York, October 1961, Nagy had shown chemical and mineralogical data pointing to the possibility that there

H. C. Urey, *Science* **137**, 623-628 (1962)

In the **SCI**, this subject is identified by the specific citation:

**UREY HC-----62-SCIENCE----- 137 623**

To find where a specific paper, book, thesis or technical note, etc. has been cited in a current journal article, look in the **Citation Index** section of the **SCI** under the specific citation.

CITED AUTHOR	CITING AUTHOR	CITED PUBLICATION YR	CITING PUBLICATION YR	VOL	PAGE
UREY HC		62-SCIENCE	65	137	623
WEN T	J CHEM PHYS	55	42	932	
PILLAT HOK	AUST J CHEM	55	38	261	
TAKAGORO H	J CHEM PHYS	55	52	2532	
DOAN RL	GEOL SOC AM	65	76	282	
MUELLER G	NATURE	205	1209	1200	
ANDERS E	SPACE SCI R	8	64	3	593

**CITATION INDEX SECTION**

Any article cited during the period indexed is listed alphabetically under the first author's name. Each cited work by that author is arranged chronologically and indicated by a dashed line. ■ Beneath the cited item, you will find the list of current citing articles. In this instance, the 1962 article by H. C. Urey in *Science* **137**, 623 was cited, in 1965, by G. Mueller, *Nature* **205**, 1200. ■ Each citing item, other than journal articles, is characterized by a code indicating whether it is a review article, letter, correction, book review, meeting proceedings, editorial, etc. In this example "L" is the code for "letter."

To find the articles and other items published by a specific organization, look in the **Corporate Index** under the organization's name.

U LOND BEPP COLL REGENTS PARK	J CHEM SOC	65	1912
BADAR Y	J CHEM SOC	N 65	1543
U LOND BEPP COLL GEORG SENT LAB LOND	CHEM SOC	65	643
U LOND BEPP COLL	NATURE	65	265 575
MUELLER G	NATURE	205	1200
U LOND BEPP COLL DEP CHEM LONDON	J CHEM SOC	65	958

**CORPORATE INDEX SECTION**

To find the full titles, co-authors and bibliographic data for the citing works or works attributed to an organization, look in the **Source Index** under the first author's name.

MUELLER GW	RAD CORP AM	65	P	28	JAN 19
316659 US	6517/235	SYMMETRICAL POWER TRANSISTOR			
MUELLER DC	INT BUS MACH	65	P	28	JAN 12
3165718 US	6548/165	MATRIX OF COINTEGRATE GATES HAVING COLUMN AND ROW SELECTION			
MUELLER EG	SEE SMITH HL	3166563 US			
MUELLER FH	MUELLER CD	65	P	18	FEB 2
3166280 US					
MUELLER G	CLAUS G	SURAC EA			
NATURE	205	1209	65	L 10R	NA-977 62558
INTERPRETATION OF MICRO-STRUCTURES IN CARBONACEOUS METEORITES					
MUELLER G	STROTT W	65	P	18	FEB 2
Z PHYS	202	366	65	229	NA 51957
THERMOLUMINESCENCE AND EXO-ELECTRON EMISSION FROM ALKALI SALTS					

**SOURCE INDEX WITH TITLES**

All the current articles published in the period indexed are listed alphabetically by author. ■ The full title, as in the Mueller article above, is given. All co-authors, journal, page, volume, year and the number of references it cites are given. Each item is coded, e.g. "C" for "correction," "B" for "book review," "L" for "letter," "M" for "meeting," etc. ■ The **SCI Source Index** is essentially a calendar year author index covering all the journal items processed by the closing date for the current year. ■ All journal issues available for any given year are included in the latest **SCI Annual**. ■ The **SCI Source Index** can also be used independently of the *Citation Index*. ■ While the *Citation Index* is a *subject index*, the *Source Index* is the comprehensive *author index* of science. All co-authors are cross-referenced.

**CORPORATE INDEX SECTION**

Under each organization you will find the citations for all items attributed to that organization which were published during the period indexed. ■ In this example, the 1965 article by Mueller is listed under *University of London, Birkbeck College*, with other articles attributed to that institution.

A key advantage of citation indexing from the outset was its capacity to bypass the use of normal linguistic forms such as title words, keywords, or subject headings. In 1978, Henry Small described the symbolic role played by the citation in representing the content of papers.<sup>23</sup> In combination with various natural language expressions, citation indexes greatly improve comprehensive literature searches. I have often described the *SCI* as a tool for navigating the literature<sup>24</sup> but the fundamental retrieval function of the citation index is to enable the searcher to locate the subsequent and especially the current descendants of particular papers or books. Each starting paper is used to symbolize a unique concept, from the simplest to the most complex of ideas or procedures. The *Citation Index* user frequently wants to focus initially on retrieving only those papers that have cited that primordial work. Once the citing papers are retrieved, the scope of the search can be expanded by using the papers they cite or other related papers as entry points to the *Citation Index*. These starting references can also be supplemented by using the *Permuterm*<sup>®</sup> *Subject Index* section of the *SCI*<sup>25</sup> or other keyword indexes.

### Citation Consciousness

In principle, all scholars and editors ought to be asking about any publication of interest to them, "Has it been cited elsewhere?" Such citation consciousness is especially important when reviewing what is cited in newly submitted manuscripts. The routine exercise of the cited reference search in the citation index would help prevent much unwitting duplication and the alleged widespread failure to cite relevant literature.<sup>26</sup> John Martyn's classic study in 1963 indicated that there was 25% inadvertent duplication in research.<sup>27</sup> In any event, routine checks of citation and other indexes would help reduce such duplications. The attention recently devoted to misconduct in science has given greater impetus to the notion that authors should explicitly declare that they have searched the literature.<sup>28</sup> The issue of "When to Cite" is complex.<sup>29, 29</sup>

A fundamental dilemma arises when routine searches of citation indexes are based on what is cited in new manuscripts. How will the search identify highly relevant references that are not known to the author or the referees and were not found by traditional keyword or *KeyWords Plus*<sup>30</sup> searches? Experience tells us that relevant material is frequently missed. An idea can be expressed in many different ways that defy the normal search procedure. The advantage of citation indexing in overcoming these linguistic barriers has been extensively discussed and documented; Henry Small's review of the citation as symbol, mentioned above, is only one example.<sup>23</sup>

The answer to the dilemma is found in the natural redundancy of reference lists. Each new research manuscript, depending upon the field, normally contains from 15 to 35 references. What is the chance that a "missing" relevant reference will not be found by searching citation indexes to determine whether any of the papers cited by the author are cited elsewhere? Such procedures have sometimes been called "cycling."<sup>31</sup>

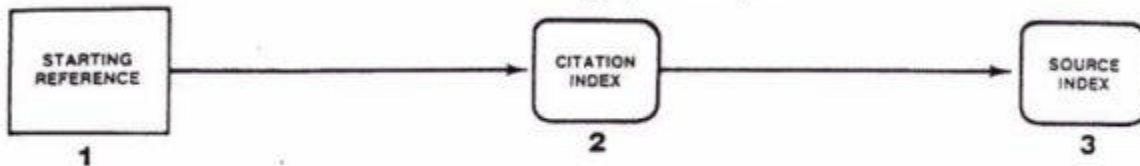
## Routine Citation Checks in Refereeing

FIGURE 2: BASIC SEARCH TECHNIQUE WITH STARTING REFERENCE

### BASIC SEARCH TECHNIQUE

To perform a basic literature search with the Science Citation Index®:

- 1** *Begin with a work on the subject known to be pertinent. . . .*
- 2** *Enter the appropriate Citation Index Section and find a list of current works which cite the starting reference*
- 3** *In the Source Index, look up those current works you have found and find their full titles and complete bibliographic descriptions*



*Note: If for any reason the procedure described above does not fulfill your searching objective, refer to the diagram given below for alternative procedures*

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#### *Additional Searching Methods*

- 4** *If you wish to extend the search, you may use the source article retrieved or a reference from its bibliography as a new starting reference.*
- 5** *The author of your starting reference may have written other works which are cited. These may also be used as starting references.*
- 6** *The titles of the source articles which cite the starting reference will indicate the main theme of the citing article. The Source Index may also reveal additional current works on the subject of your search by the same author. You may also be led to other pertinent works where he was co-author.*
- 7** *If your starting reference is not cited, select pertinent references from its bibliography.*

FIGURE 3: WITHOUT STARTING REFERENCE

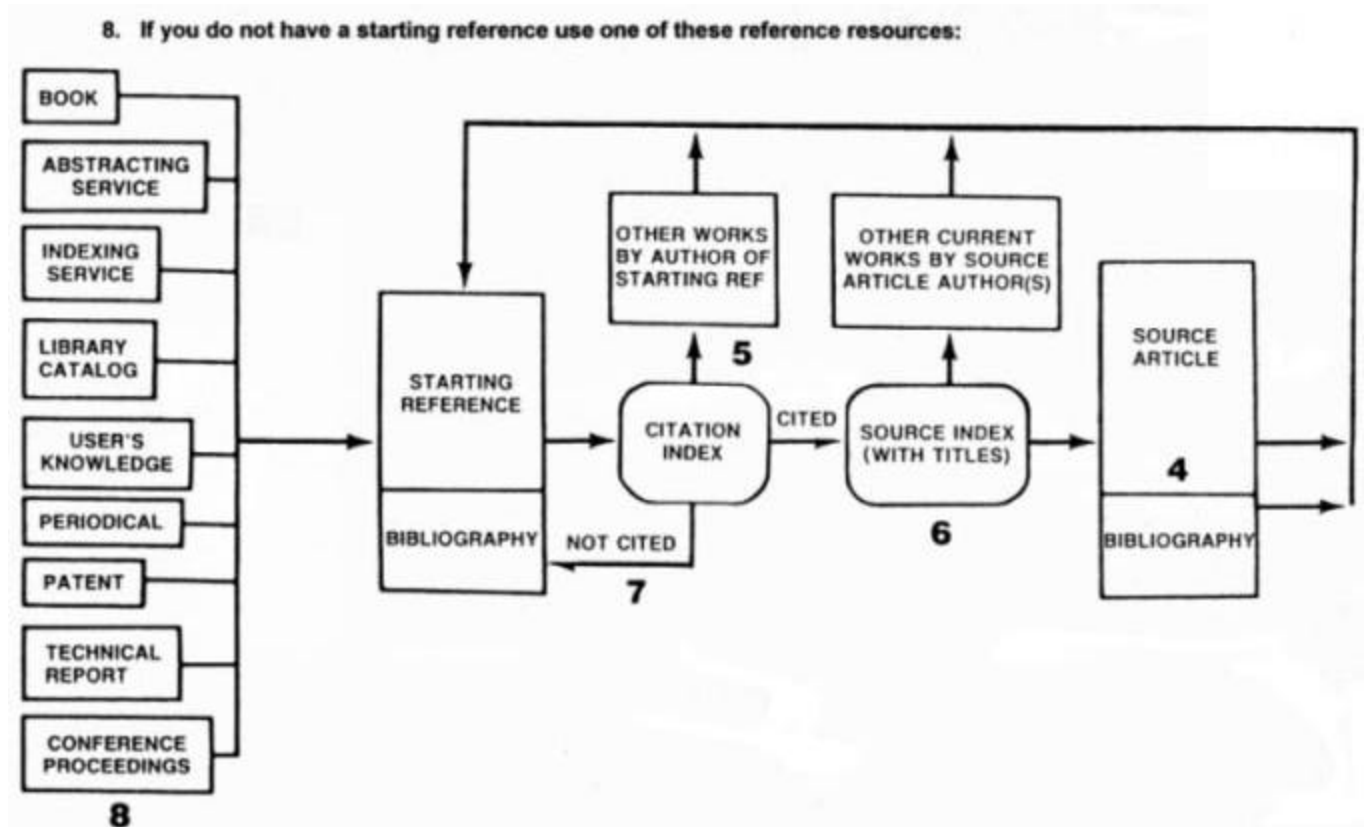
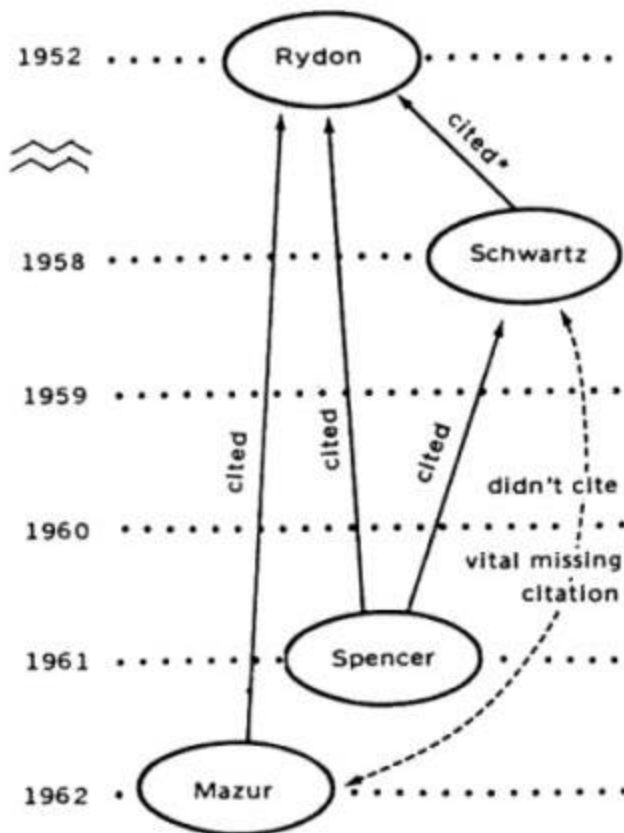
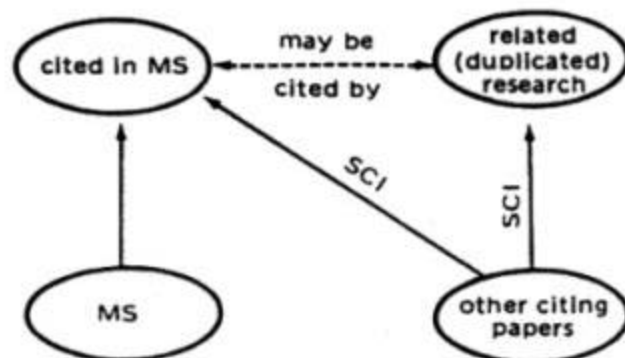




FIGURE 4: SCI SEARCH FOR DUPLICATED RESEARCH

SCI<sup>®</sup> SEARCH FOR DUPLICATED RESEARCH  
MAZUR-SCHWARTZ



One of the earliest examples I used to demonstrate cycling<sup>20, 32</sup> involved an apology published in *Analytical Chemistry*. The authors<sup>33</sup> had not known about another paper<sup>28</sup> that had *anticipated* their work. Upon examining the two papers in question, I observed that half of the references they cited had also been cited by the earlier authors. This co-citation pattern is quite common, indeed pervasive, in scholarship. Its prevalence enabled Henry Small and others to use co-citation as a reliable means of tracing and mapping specialty literatures.<sup>35</sup> Referees and editors ought to be asking authors not only whether a traditional key-word search has been performed, but also whether the author's own bibliography has been subjected to citation searches.

**Current Awareness**  
**FIGURE 5: RESEARCH ALERT**

J AM S IN INFORMATI RETRIEVAL MONITOR/	RETHINKING ONLINE MONITORING METHODS FOR INFORMATION-RETRIEVAL SYSTEMS - FROM SEARCH PRODUCT TO SEARCH PROCESS Borgman CL Hirsh SG Hiller J 77 REFS J AM S INFO 47(7): 568-583, JUL 1996
LANCASTER FH SHUTE SJ BARRY CL TOLLE JE	THESE ITEMS IN YOUR PROFILE WERE CITED: INFORMATION RETRIEVA 93 INFORM PROCESS MANAG 29 29 93 J AM SOC INFORM SCI 45 124 94 P AM SOC INFORM SCI 21 126 84 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO254 CL BORGMAN, UNIV CALIF LOS ANGELES, GRAD SCH LIB & INFORMAT SCI, DEPT LIB & INFORMAT STUDIES, 2320A MOORE HALL, LOS ANGELES, CA 90095
J AM S IN	RETRIEVAL IN MEDICINE AND HUMAN INDEXING (VOL 47, PG 407, 1996) (CORRECTION) Humphrey SM 1 REFS J AM S INFO 47(7): 584, JUL 1996
HUMPHREY SM	THESE ITEMS IN YOUR PROFILE WERE CITED: J AM SOC INFORM SCI 47 407 96 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO254
RES POLIC	EFFECTIVENESS OF R-AND-D SUBSIDIES - A SKEPTICAL NOTE ON THE EMPIRICAL LITERATURE Kauko K 12 REFS RES POLICY 25(3): 321-323, MAY 1996 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO233 K KAUKO, CIBR, TOOLONKATU 11, SF-00100 HELSINKI, FINLAND
RES POLIC	ASSESSING VALUE-ADDED CONTRIBUTIONS OF UNIVERSITY TECHNOLOGY BUSINESS INCUBATORS TO TENANT FIRMS Mian SA 24 REFS RES POLICY 25(3): 325-335, MAY 1996 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO233 SA MIAN, SUNY COLL OSHEGO, SCH BUSINESS, OSHEGO, NY 13126
RES POLIC	R-AND-D STRATEGY IN A TECHNOECONOMIC NETWORK - ALZHEIMERS-DISEASE THERAPEUTIC STRATEGIES Penan H 23 REFS RES POLICY 25(3): 337-353, MAY 1996
WHITE H (GRIFFITH) WHITE HD GARFIELD E GARFIELD E LEYDESORFF L COURTIAL JP COURTIAL JP CALLON M	THESE ITEMS IN YOUR PROFILE WERE CITED: J AM SOC INFORM SCI 32 163 81 J AM SOC INFORM SCI 32 163 81 CURR CONTENTS 39 77 CURR CONTENTS 39 77 SCIENTOMETRICS 25 295 92 SCIENTOMETRICS 25 313 92 SCIENTOMETRICS 15 527 89 SCIENTOMETRIE QUE SA 93 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO233 H PENAN, ECOLE MINES, CSI, 62 BVD ST MICHEL, F-75006 PARIS, FRANCE
RES POLIC	A MORPHOLOGY OF JAPANESE AND EUROPEAN CORPORATE RESEARCH NETWORKS Hicks DM Isard Pa Martin BR 24 REFS RES POLICY 25(3): 359-378, MAY 1996
KATZ JS	THESE ITEMS IN YOUR PROFILE WERE CITED: SCIENTOMETRICS 31 31 94 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO233 DM HICKS, UNIV SUSSEX, SCI POLICY RES UNIT, BRIGHTON BN1 9RF, E SUSSEX, ENGLAND
RES POLIC	THE INNOVATION OF AGROCHEMICALS - REGULATION AND PATENT PROTECTION Hartnell G 44 REFS RES POLICY 25(3): 379-395, MAY 1996 -----> CHECK TO ORDER THE ARTICLE ----->( ) #UO233 G HARTNELL, UNIV SUSSEX, SCI POLICY RES UNIT, PROGRAMME ENVIRONM POLICY & REGULAT, FALMER, BRIGHTON BN1 9RF, E SUSSEX, ENGLAND

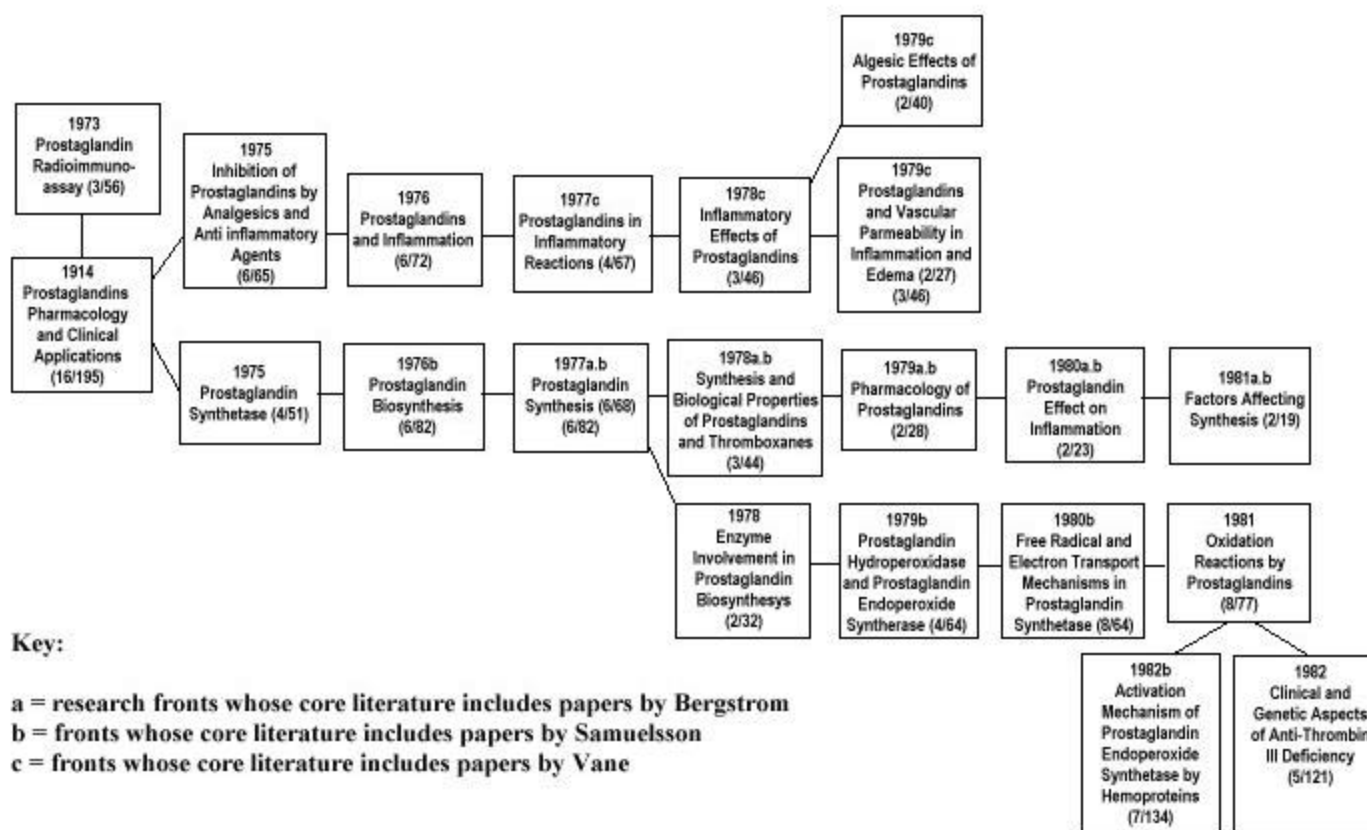
**Research**  
**ALERT**

Apart from its widespread use for information retrieval and in evaluation research, citation indexing has two other uses that deserve special mention. The first is in selective dissemination of information. Over 25 years ago, Irving Sher and I published the first papers on *ASCA* (Automatic Subject Citation Alert),<sup>36, 37</sup> now called *Research Alert*<sup>®</sup>. This system of selective dissemination of information (SDI) involves matching combined reference, keyword, and author profiles of each new paper with a user's search profile of references, terms, and authors. The system enables thousands of searchers to be alerted to new papers that have cited any one or more of the terms in their personal profiles, including their own or related authors' work. It is hard to understand why this type of scientific clipping service is not more widely used. However, variants of SDI profiling have been adopted in many on-line search systems, mainly using keywords, descriptors, or subject headings, as in Medline. The comparable *SCI*-based system is called *SciSearch*<sup>®</sup> and is available on several systems including Dialog, STN, etc.

## History of Contemporary Science

FIGURE 6: HISTORIOGRAPH

### PROSTAGLANDINS HISTORIOGRAPH 1973-82



A second further use of citation indexing is in writing the history of contemporary science. The *Science Citation Index*<sup>®</sup> source material now covers fifty years of the literature from 1945 to the present and thus provides a major tool for the contemporary history of science. There have been about 25 million papers published since the end of World War II, containing at least 250 million cited references. In spite of the huge number of these reference links, the complete citation network can be stored in about 20 gigabytes of computer memory. Such a complete file is not yet available electronically but could be created from ISI's master tapes. The *SCI* print edition covers 1945 to the present while 1980 to the present is also available on CD-ROM. The on-line version *SciSearch* is available on DIALOG and STN from 1974 onward. The *Social Sciences Citation Index*<sup>®</sup> (SSCI<sup>®</sup>) is available from 1955 onward in similar print, CD-ROM and on-line editions. The *Arts and Humanities Citation Index*<sup>®</sup> begins with the 1975 literature.

## This Week's Citation Classic

CC/NUMBER 42  
OCTOBER 20, 1980

Vane J R. Inhibition of prostaglandin synthesis as a mechanism of action for aspirin-like drugs. *Nature New Biol.* 231:232-5, 1971.

[Department of Pharmacology, Institute of Basic Medical Sciences, Royal College of Surgeons of England, Lincoln's Inn Fields, London, England]

The generation of prostaglandins by a cell-free enzyme preparation *in vitro* was measured by bioassay. Aspirin-like drugs inhibited the formation of prostaglandins. This enzyme inhibition was proposed as the mechanism of therapeutic action and side effects of aspirin-like drugs, implicating prostaglandins in inflammation. [The *SCI*<sup>®</sup> indicates that this paper has been cited over 1,915 times since 1971.]

John R. Vane  
Wellcome Research Laboratories  
Langley Court  
Beckenham, Kent BR3 3BS  
England

July 17, 1979

"The aspirin-like drugs are not only amongst the most widely used synthetic pharmaceuticals but also amongst the oldest. Even so, there was no widely accepted theory to explain their actions. The drugs' three salient properties—anti-pyresis, anti-inflammation, and analgesia—seemed unrelated to one another as did their shared side effects.

"The discovery that aspirin and similar compounds prevented the biosynthesis of prostaglandins (PGs) suggested that this enzyme inhibition accounted for their therapeutic effects. It came at a time when interest was burgeoning in prostaglandins, which had already been detected in inflammatory exudates and shown to mimic some of the signs and symptoms of inflammation.

"The finding was a consequence of our development of a method of parallel bioassay which allowed the immediate and continuous detection of the release of vasoactive substances, such as histamine, serotonin, epinephrine, bradykinin, and some of the PGs. The method had the advantage of simplicity and allowed the maximum opportunity for serendipity. We were

using this technique to study the release from lungs of putative mediators of anaphylaxis, and found some unexpected ones—PGE<sub>2</sub>, PGF<sub>2α</sub> and an ephemeral substance which we called 'rabbit aorta contracting substance' or RCS. Aspirin abolished the output of RCS (nowadays known as thromboxane A<sub>2</sub>). Later experiments using a different system showed that aspirin also abolished the release of PGs. Whilst working on a review over the weekend, I realized that stimulated tissues released more PGs than they contained, equating release with stimulation of biosynthesis. Could aspirin be preventing PG biosynthesis? On that Monday morning I said to my colleagues, 'I think I know how aspirin works.' I told them my hypothesis and set about experimenting to put it to the test. The most direct test of whether aspirin inhibited prostaglandin biosynthesis was to make an *in vitro* preparation of the enzyme involved. As a classical pharmacologist, I had always been taught to study whole tissues, rather than smash them into bits. However, I found a paper describing prostaglandin synthetase made from homogenised lungs<sup>1</sup> and on that same day made my very first enzyme preparation. It worked, and so did aspirin as an inhibitor!

"The forging of the aspirin-prostaglandin link was important for several reasons. First, it established a scientifically satisfactory mode of action for aspirin-like drugs, now generally accepted. Secondly, it provided a simple enzyme test for discovering new, and hopefully better, aspirins. Thirdly, it provided a tool by which biologists could study the importance of prostaglandins in the body's processes. Give an aspirin-like drug, see what it does to a particular organ or function and that tells you what a lack of prostaglandins does. Fourthly, from the elucidation of the role of prostaglandins in the body, it suggested new uses for aspirin-like drugs."

1. Anggård F & Samuelsson B. Biosynthesis of prostaglandins from arachidonic acid in guinea pig lung. *J. Biol. Chem.* 240:3518-21, 1965.

Using the full *SCI/SSCI/AHCI*<sup>®</sup> files one can trace an uninterrupted path covering fifty years for almost any designated paper. Nevertheless, there is little evidence that scholars conduct such searches. I myself have regularly used a derivative of this huge file to identify putative *Citation Classics*. This internal ISI file can be used to find the papers most cited for 1945-92 in the *SCI/SSCI* above a specified threshold. The file is sorted by author or journal.

### FIGURE 7 : VANE CITATION CLASSIC

Over a fifteen-year period, authors of about 10,000 candidate *Citation Classics* were asked to comment on their highly cited papers or books.<sup>38</sup> About 50% responded and their responses were published in *Current Contents*<sup>®</sup>; about 2,000 of these commentaries were reprinted in 1984 in a seven-volume series titled *Contemporary Classics in Science*.<sup>39</sup> Companario recently used a "sample" of these "most-cited" papers to examine, e.g., patterns of initial rejection by leading journals for papers published elsewhere.<sup>40</sup> A major study of women in science also relied on this database.<sup>41</sup> It has been somewhat disappointing to see how few journal editors have chosen to use these journal files to identify their landmark papers.<sup>42, 43</sup>

Perhaps this reluctance by editors is connected to a more general hostility toward and distrust of quantitative methods in peer review. The point of examining lists of most-cited papers is not to claim dogmatically that they are the "best," but rather to make certain that various evaluation processes do not overlook high-impact work that otherwise might be ignored by members of awards or other evaluation committees. It is equally important for such groups to determine why certain papers deemed to be seminal to a field have not been cited at levels one might have expected. Was this due to obliteration by incorporation<sup>44, 45</sup> or to other factors in the history of these relatively uncited landmark papers?

### Emergence of Scientometrics

A new sub-specialty known as "scientometrics" has developed because of the availability of the ISI citation indexes. Derek de Solla Price was one of the first to recognize the potential of citation analysis for science-policy related studies, and thus helped found scientometrics. His mentor, J.D. Bernal, referred to such studies as the science of science. Countless scientometric analyses have been published as separate papers while many others are simply incorporated into papers that support scientific, scholarly or policy arguments of one kind or another.

There has been much ado about the applicability of citation data, but this varies at the level of aggregation chosen. The national and regional indicators reported by the NSF over a twenty-year period have used *SCI* data to identify trends of one kind or another.<sup>46</sup> Such statistical reports by country or discipline also appear regularly in publications like *Science Watch*<sup>®</sup> or *Scientometrics*. Citation analysis becomes controversial mainly when it is used as a tool in making decisions about funding or the tenure of individuals or groups, especially when it is perceived to be an uninformed use of citation data. Many of these unpublished citation analyses, like most unrefereed work, may, in fact, involve the abuse of *SCI* data and rightly evoke hostility or unease. After all, some highly published authors are little more than bureaucrats who attach their names to every paper they can. Unless such details are known to the evaluators, citation data could be used to perpetuate unjust distribution of resources. Various forms of inappropriate authorship appear in a recent discussion of scientific misconduct.<sup>47</sup>

But the opposite may also be true. In several countries where research funding is often highly political, many of the most deserving researchers receive a small fraction of research funds in contrast to parasites who hadn't published a paper for a decade or more. Many well-funded clinical researchers publish in obscure national journals in the local language to hide their lack of international significance. In contrast, younger researchers not only publish in the international

journals but are also well cited. Their impact on their scientific fields becomes clearly visible through citation analysis.

### **Old Boy Network**

In science, as in other areas of life, "awards" and elections to academies are usually made by committees, sometimes described as "old boy networks". Unless they are regularly refreshed with new members, they tend to rely on biased human memory in making their selections. Such fossilized groups rarely ask for outside nominations or subject their choices to informed confirmation. The routine use of citation analysis in the award process can ameliorate such situations and should include consideration of appropriate cohort candidates for the innumerable awards in science. The routine use of citation analysis should uncover those individuals who have been inadvertently or otherwise overlooked in the nomination process. And, in some cases, where certain pioneers are selected late for awards, the citation history should demonstrate that their basic work was premature<sup>48</sup> -- that many years had elapsed before it was widely recognized.

It is often asserted that citation analysis does not adequately recognize small fields. It is rare indeed for a Nobel Prize or a Lasker, Wolf, or Gairdner award to be awarded in fields so small that the citation impact of the candidates is not above average or otherwise recognizable. To avoid injustice to smaller fields, the *SCI* files should be sub-divided or categorized as was the case, e.g., in radio astronomy.<sup>49, 50</sup> Papers and authors with above-average impact will stand out from others in the cohort. Arno Penzias was not necessarily among the 1,000 most-cited scientists but he was among the most-cited radio astronomers.

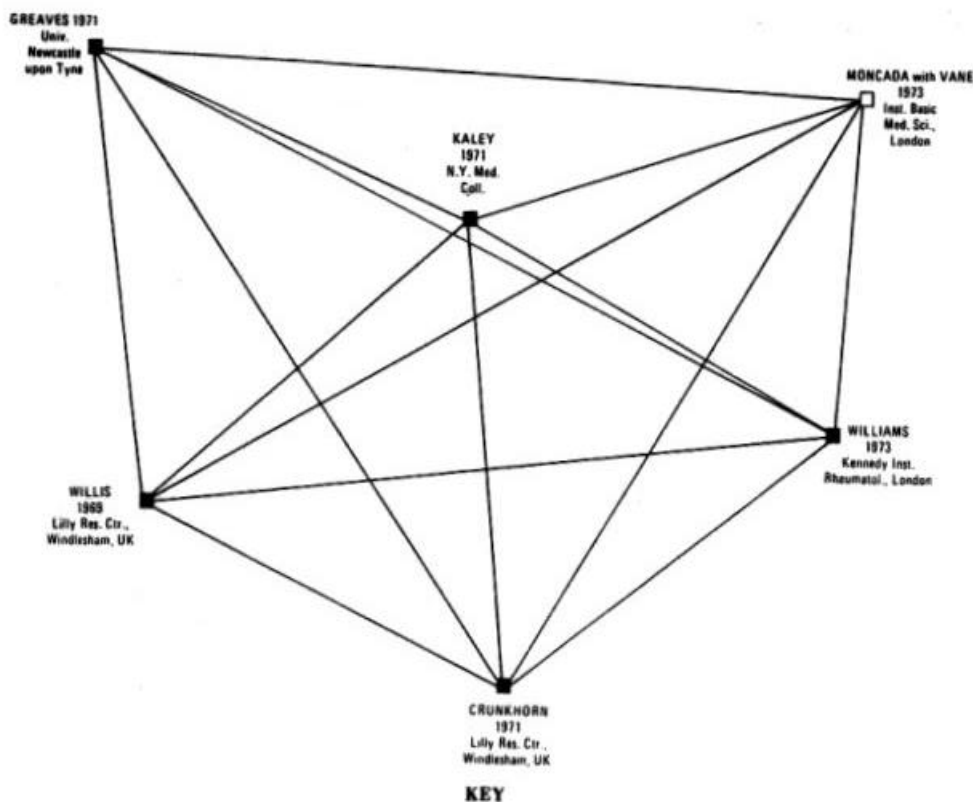
### **Identifying Research Fronts**

To use citation data properly, one needs a procedure for identifying the fields, especially small fields. From the earliest days of our work in indexing and classification, it was recognized that the process of field identification is highly problematic. With the pioneering work in 1973<sup>35</sup> of Small, and Marshakova,<sup>51</sup> we entered the era of algorithmic classification. The use of co-citation analysis for the identification of research fronts made it possible to systematically identify small and large fields. While a research front can emerge from a single seminal work, normally two or more of core papers are involved in the identification of new fronts.<sup>34</sup>

**FIGURE 8: CO-CITATION OF CORE PAPERS FOR "PROSTAGLANDINS AND INFLAMMATION."**

While co-citation analysis has been used systematically by ISI to identify en masse thousands of

**MULTIDIMENSIONAL SCALING MAP SHOWING CO-CITATION LINKS BETWEEN CORE PAPERS OF THE 1976 SCI RESEARCH FRONT #76-869, "PROSTAGLANDINS AND INFLAMMATION"**



**KEY**

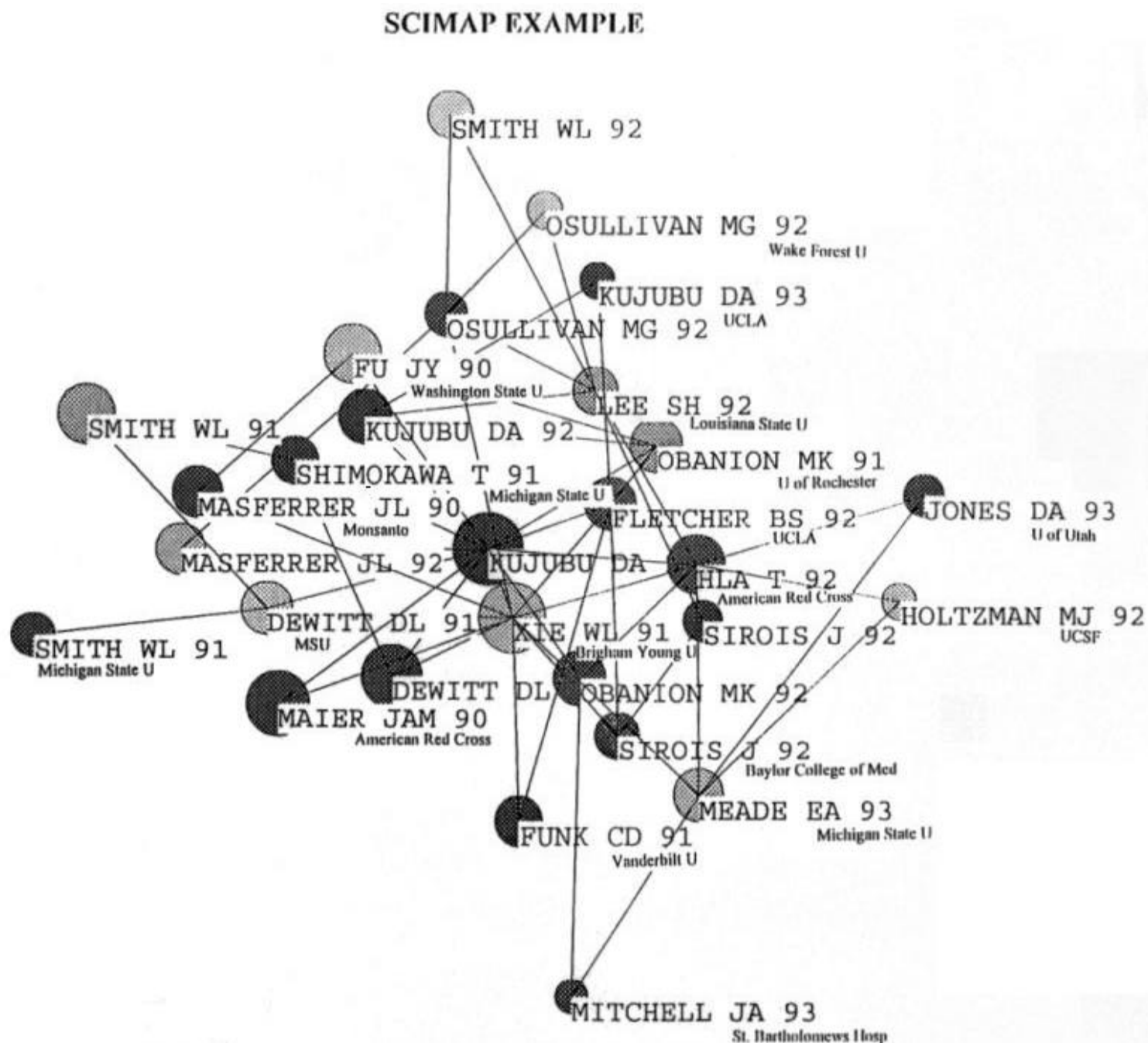
Crunkhorn P & Willis A L. Cutaneous reactions to intradermal prostaglandins. *Brit. J. Pharmacol.* 41:49-56, 1971.  
 Greaves M W, Sondergaard J & McDonald-Gibson W. Recovery of prostaglandins in human cutaneous inflammation. *Brit. Med. J.* 2:258-60, 1971.  
 Kaley G & Welner R. Prostaglandin E<sub>1</sub>: a potential mediator of the inflammatory response. *Ann. NY Acad. Sci.* 180:338-50, 1971.  
 Moncada S, Ferreira S H & Vane J R. Prostaglandins, aspirin-like drugs and the oedema of inflammation. *Nature* 246:217-9, 1973.  
 Williams T J & Morley J. Prostaglandins as potentiators of increased vascular permeability in inflammation. *Nature* 246:215-7, 1973.  
 Willis A L. Letter to editor. (Parallel assay of prostaglandin-like activity in rat inflammatory exudate by means of cascade superfusion.) *J. Pharm. Pharmacol.* 21:126-8, 1969.

research fronts each year, a similar procedure called co-citation mapping can also be used to create ad-hoc clusters maps. In short, one can construct the map of core papers for any specialty by establishing the citation linkages between groups of papers associated with any individual or group under consideration. Indeed, it might be argued that unless one has actually or implicitly created the map of an individual's specialty, one cannot say with assurance whose role was primordial. Such maps can be created to cover short or long periods. It would be an anomalous situation if a deserving scholar's work did not to turn up as one of the key nodes on the map of his or her field.

Indeed, such key links need not be based on high citation frequency. As Sher, Torpie, and I demonstrated over 30 years ago, careful citation mapping leads to the uncovering of small but important historical links overlooked by even the most diligent scholars.<sup>52</sup>

Henry Small's SciMap software is now routinely used to create these maps for small databases extracted from the ISI indicators files for 1981-95.

**FIGURE 9: SCIMAP OF PROSTAGLANDIN SYNTHASE**



### Uncitedness

A frequent topic, given prominence in 1990 by a reporter for *Science*,<sup>53</sup> is that of uncitedness; that is, failure of publications to be cited at all, or rarely. The truth is that we know too little about uncitedness. Hamilton<sup>53</sup> garbled some unpublished data he was given without recognizing the details to be worked out. He used these data to support his preconceived notions about the



alleged lack of utility of large areas of scholarly research. Pendlebury published a note in *Science* which attempted to correct the false impression created,<sup>54</sup> but like so many other published errors, Hamilton's report continues to be cited while Pendlebury's "correction" is mainly overlooked.

Regardless of what is done about the selective funding of research, there will always be skewed distribution in citation frequency. The vast majority of published papers will always remain infrequently cited. These Pareto- or Lotka- type distributions of citation "wealth" are inherent in the communication process so well described by Derek Price.<sup>55</sup> As a result, there are inevitable discontinuities in scholarship. A small percentage of the large mass of poorly cited material may include some work that can be described as "premature" in the sense of being valid and important but not recognized.<sup>48</sup> It should be possible to systematically reexamine such uncited works even decades later. Presumably some have served as useful stepping stones in the evolution of a particular field. Editors can easily identify such papers and reconsider them in light of changes in the field. While it would be a daunting task to re-evaluate all previously published manuscripts for this purpose, serious thought should be given to this task. What would happen to these papers were they resubmitted in light of the changes in the past decade or two?

More than likely, many uncited papers involve supersedure. Publication of research is a cumulative process. Each new laboratory report by established investigators builds on and/or supersedes their own earlier work. As the work progresses, it is not necessary to cite all the earlier reports. It is not unusual to observe that after a decade of research, the entire corpus is superseded by a "review" which is preferentially cited by subsequent investigators.

Hamilton also ignored the more prominent fact about uncitedness; among the leading research journals of the world it is, to all intents and purposes, non-existent. The following tables provide data on cumulative citation counts for the average paper in each of the most influential scientific journals.

FIGURE 10: CUMULATIVE IMPACT OF 1981 ARTICLES AND UNCITEDNESS  
CUMULATIVE IMPACT AND UNCITEDNESS

1981 ARTICLES CITED 1981-93						
1981 Articles 1981 1981 1981						
Av Cum Cites Cited % Total						
1981-93 Items Uncited Cites						
Rank	Journal #	Items (All)	(Cited)			
1	Cell	393	126	126	0	49,307
2	NEJM	378	116	117	1.06	43,784
3	J Exp Med	343	89	90	0.29	30,630
4	PNAS (Biol)	1550	86	86	0.13	133,135
5	J Cell Biol	367	81	81	0	29,629
6	Arch Gen Psych	152	79	80	1.31	11,970
7	J Clin Invest	418	77	78	0.48	32,226
8	Nature	1375	71	73	2.76	96,881
9	J Neurosci	106	70	70	0	7,432
10	Science	1077	61	64	4.36	65,831
11	J Mol Biol	307	61	61	0.99	18,629
12	J Immunol	989	55	55	0.2	54,380
13	Circulation	416	54	55	1.92	22,601
14	Circulation Res	267	54	54	0	14,439
15	Ann Int Med	290	54	55	2.1	15,528
16	Blood	360	53	53	0	18,983
17	Lancet	641 <sup>a</sup>	52	69	25.6	33056
18	JBC	2220	49	49	0.59	108,107
19	Gastroenterology	325	47	48	1.23	15,408
20	Mol Cell Biol	122	47	47	0.81	5,713
21	Phys Rev L	992	43	43	0.4	42,463
22	Syst Zool	34	43	44	2.86	1,455
23	Am J Pathol	167	42	43	1.19	7,053
24	Eur J Immunol	171	42	43	2.33	7,156
25	Cancer Res	851	37	37	0.59	31,245
26	Ann Neurol	222	37	38	2.69	8,131
27	Lab Invest	139	36	36	0.71	4,952
28	J Virology	483	32	33	0.83	15,558
29	J Natl Canc I	306	31	31	0.65	9375
30	Arthritis Rheum	204	27	28	2.44	5,577
31	Am J Hum Genet	78	24	25	1.27	1,896
32	Angew Chem	413	21	22	2.66	8,664
33	JAMA	551	21	23	9.2	11,382

a - Includes "Notes"

For each journal we have determined the percentage of uncited papers. As we see, well over 90-95% of this literature is well cited. The cumulative citation frequency for these journals is indeed startling. By definition, as one reaches down into the many smaller and lower impact journals, the percentage of uncitedness increases.

Other important facets of low-frequency citation would be the consequence of an obliteration by incorporation (OBI) into review articles.<sup>44,45</sup> There are hundreds of review journals which incorporate into their coverage thousands of stepping-stone papers which form the building blocks of scientific knowledge. Consider, e.g., that the *Annual Review of Biochemistry* published approximately 250 papers over the decade 1981-90. These reviews contained about 40,000 cited references, but more importantly, each review itself has been cited in over 300 subsequent papers. This is detailed in Figure 2.

**FIGURE 11: CUMULATIVE IMPACTS FOR ANNUAL REVIEW OF BIOCHEMISTRY**

<b>ANNUAL REVIEW OF BIOCHEMISTRY</b>	
<b>YEAR-BY-YEAR CUMULATIVE IMPACT</b>	
<b><u>Year</u></b>	<b><u>Cumulative Impact</u></b>
1981	329
1982	251
1983	391
1984	370
1985	312
1986	300
1987	520

FIGURE 12: CUMULATIVE IMPACT FOR 1981-6 REVIEW JOURNALS ARTICLES FROM 1981-94  
 CUMULATIVE IMPACT 1981-94  
 Review Journal Articles  
 Published 1981-6  
 6-Year Total Total  
 JOURNAL Average Citations Source

ANN R BIOCH	320.31	60219	188
ANN R CELL	231.35	7866	34
ADV PROTEIN	205.29	4311	21
ANN R IMMUN	194.59	16929	87
PHYSIOL REV	176.53	22066	125
REV M PHYS	167.85	21821	130
ADV IMMUNOL	159.19	6686	42
MICROBIOL R	145.28	18015	124
ANN R NEUR	141.6	13877	98
PHARM REV	138.26	10646	77
ANN R PLANT	138.22	17139	124
ANN R GENET	131.99	13199	100
ENDOCR REV	128.49	17731	138
ADV PHYSICS	108.93	6318	58
ANN R PHARM	107.59	15493	144
ADV CARB C	96.8	3388	35
ANN R ASTRO	94.43	8782	93
ADV O R G M ET	90.62	3534	39
CHEM REV	90.54	13853	153
BIRAIN RES R	89.74	9602	107
ANN R PH CH	85.64	10277	120
IM.MUNOL REV-	80.12	22753	284
Q REV BIOPH	77.37	3946	51
REV PHYS B	76.94	3847	50
ANN R PHYSL	75.35	20722	275
PROG NUCL	74.16	2373	32
PSYCHOL REV	73.71	11646	158
CRC C R BI	72.47	7754	107
AN N R ECO L	70.42	8239	117
REC PROG H	70.05	4273	61
ANN R MICRO	68.73	9829	143
ACC CHEM RE	68.44	23887	349
ANN R BIOPH	65.31	7184	110
ADV ENZYM	56.98	2963	52
EPIDEMIO L R	53.32	3039	57
PHYS REPO RT	52.06	24259	466

After the 1979 publication of my book on *Citation Indexing*,<sup>31</sup> an excellent review of the literature was published in 1981 by Linda Smith.<sup>56</sup> Then in 1984 Blaise Cronin published *The Citation Process*, an excellent account of citation behavior and related issues.<sup>57</sup> Subsequently, White and McCain,<sup>58</sup> and Cozzens<sup>59</sup> provided additional reviews.

## Conclusion

It is commonplace to speak about the isolation of the cultures of science and social science. Most practicing scientists seem completely oblivious to the large literature of citation and bibliometric studies. This synoptic review has only touched the highlights.

From the perspective of the social scientist or humanities scholar, the failure to include monographs as sources in the ISI citation indexes may be a drawback in drawing conclusions about the impact of certain work.<sup>60</sup> Nevertheless, the inclusion of books as cited references in ISI's citation indexes has permitted studies of most-cited books to be accepted as reasonable surrogates for more comprehensive studies that might have included books as sources. Undoubtedly, the creation of a Book Citation Index is a major challenge for the future and would be an expected by-product of the new electronic media with hypertext capability!

Future citation index databases will include the all-author feature so frequently missed by those who use the present generation of citation indexes. This capability is already built into the ISI Research Indicators database for 1981-95. Back in 1963 Michael Kessler introduced the notion of bibliographic coupling,<sup>61</sup> that is, retrieval of related papers, by examining the cited references they share in common. This capability awaited the implementation of large computer memories. It is now available in the form of "related records" in the *SCI* CD-ROM editions. This feature enables researchers to navigate (hypersearch) from one document to another in real time. Combined with access to full texts of papers on-line in the near future, the navigational and retrieval capabilities of citation links will finally come into full bloom. Citation analysts will then have at their disposal citations in context so that quantitative data can be augmented in real time with qualitative statements about the works being cited.

Let me conclude by quoting a recent page by Jeff Biddle at Michigan State University:

"Citation analysis is one potentially useful tool for the researcher interested in the history of twentieth-century economics and will be most useful when used in conjunction with the more traditional methods relied upon by historians... [citation analysis can be compared to] playing the role of a fallible witness. The historian who relies only on the testimony of the citation record is risking serious error, but the historian who fails to make use of it may be bypassing a valuable source of information."

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