PERSPECTIVES
INTERNATIONAL MICROBIOLOGY (2007) 10:65-69
DOI: 10.2436/20.1501.01.10 ISSN: 1139-6709 **www.im.microbios.org**
INTERNATIONAL MICROBIOLOGY

The evolution of the Science Citation Index

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Introduction

The *Science Citation Index* (*SCI*®) was first promulgated in *Science* in 1955, as an up-to-date tool to facilitate the dissemination and retrieval of scientific literature [3]. Its practical realization was possible thanks to the already-existing information service, *Current Contents*. The early computer had made it feasible for *Current Contents* to appear each week together with its title word indexes and author address directory. In those days, conventional indexes were anywhere from six months to three years behind the literature. Nevertheless, the *SCI*'s success did not stem from its primary function as a search engine, but from its use as an instrument for measuring scientific productivity, made possible by the advent of its by-product, the *SCI Journal Citation Reports* (*JCR*) and its Impact Factor rankings.

The *SCI*'s multidisciplinary database has two purposes: first, to identify what each scientist has published, and second, where and how often the papers by that scientist are cited. Hence, the *SCI* has always been divided into two author-based parts: the Source Author Index and the Citation Index. By extension, one can also determine what each institution and country has published and how often their papers are cited. The *Web of Science*® (*WoS*)—the *SCI*'s electronic version—links these two functions: an author's publication can be listed by chronology, by journal, or by citation frequency. It also allows searching for scientists who have published over a given period of years. As an example of this, Table 1 shows the resulting list for a search of scientists who have published for 70 to 85 years.

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This article is based on a lecture given by the author at the Institute for Catalan Studies, Barcelona, on January 24, 2007.
For full text see URL http://garfield.library.upenn.edu/papers/barcelona2007.pdf

A key question often arises as to the ability of citation indexing to retrieve all the relevant work on a topic. Before the advent of molecular biology, citation practices were not nearly as standardized as they are today, and implicit citation was quite common, therefore, explicit citation of earlier relevant work could not always be found. When the *Science Citation Index* was launched in 1964, Irvin Sher and I had already begun using bibliographic citations to create topological maps which we called Historiographs, to investigate whether citation indexes could aid in writing mini-histories of scientific topics. More recently, gigabyte computer memories made it possible to write a program called *HistCite*, which accepts the output of a *WoS* search and automatically generates historiographs [www.histcite.com]. By collecting all the relevant citing papers on a subject in a *WoS* search, the collective memory of the citing authors produces a visual description of the topical history. Figure 1 shows a year-by-year historiograph created to track the implicit connection between the 1953 Watson-Crick paper on the double helix, and the 1944 work of Avery et al. on pneumococcal DNA (which Watson and Crick did not cite in their paper) [http://garfield.library.upenn.edu/histcomp/index-watson-crick.html].

The Annual *SCI Journal Citation Reports* were officially launched in 1975. The *JCR* evolved to provide a statistical summation of the Journal Citation Index, which in turn was the result of re-sorting the Author Citation Index: instead of alphabetizing the file by author name, you simply sorted the file by the names of the journals in which papers were published. When this exercise was first performed in the early 1960s, the journals already covered in *Current Contents* included those that either produced the most papers or those that were cited the most. But a simple method was needed to compare large journals such as *Nature*, *Science*, and *JAMA* with smaller but important review and specialty journals including the *Annual Reviews*, which might not be selected if only total publication

Table 1. Scientists who have published for 69 years or more

Scientist	Birth/Death	Pub Years	Years Pub
Izaak Maurits (Piet) Kolthoff (analytical chemist)	1894-1993	1917-2002	86
Michael Heidelberger (organic chemist–immunologist)	1888-1991	1909-1993	85
Melvin Guy Mellon (chemist)	1893-1993	1920-2003	84
Ernst Mayr (geneticist)	1904-2005	1923-2005	83
Michel Eugene Chevreul (chemist)	1786-1889	1808-1889	82
Carl S. Marvel (polymer chemist)	1894-1988	1917-1996	80
Joel H. Hildebrand (chemist)	1881-1983	1907-1983	77
Linus Pauling (chemist)	1901-1994	1923-1998	76
John Carew Eccles (neurophysiologist)	1903-1997	1929-1992	74
Donald Coxeter (mathematician)	1907-2003	1930-2001	72
Charles Scott Sherrington (physiologist)	1857-1952	1882-1952	71
Hans Albrecht Bethe (physicist)	1906-2005	1934-2004	71
Alexander Kossiakoff (engineer; guided missile expert)	1914-2005	1935-2005	71
Norman Hackerman (chemist)	1912	1936-2006	71
Michael DeBakey (cardiac surgeon)	1908	1937-2006	70
Gerhard Herzberg (chemist)	1904-1999	1924-1992	69
Herman Mark (polymer chemist)	1895-1992	1922-1990	69

or citation counts were taken into account [2], thus the journal "impact factor" was created. We observed that 25% of all citations in the current year's literature were to papers that were only two to three years old and so it was decided upon to use the prior two cited years as the basis for calculating a current year impact factor—the average number of citations per published paper. The term "impact factor" has gradually evolved, especially in Europe, to describe both journal and author impact. Whereas an individual author produces a small number of articles on average (although there are some phenomenally productive ones), journal impact factors generally involve relatively large populations of articles and citations. A journal's impact factor is based on two elements: the numerator, which is the number of cites in the current year to any items published in the journal during the previous two years; and the denominator, the number of substantive articles (source items) published during the same two years. The impact factor could just as easily be based on the previous year's articles alone, which would give even greater weight to rapidly changing fields or, take into account longer periods of citations and/or sources, but the measure would be less current. It is important to take into account that correspondence, letters, news stories, obituaries, editorials, interviews, and tributes are not included in *JCR*'s calculation of source items. Nevertheless, since the numerator includes citations to these more ephemeral items, some distortion will result; but ordinarily just a small number of journals will be affected, and out of those, the effect will imply a change of only 5–10% [4].

Scientometrics and journalology

Citation analysis has blossomed over the past three decades into the field of scientometrics, already possessing a specialized journal which started in 1978, *Scientometrics*, and its own International Society of Scientometrics and Informetrics (ISSI) [http://www.issi-society.info]. Over 15 years ago, Steve Lock aptly named the application of scientometrics to journal evaluation "journalology" [10].

All citation studies should be normalized to take into account variables such as discipline, half-life, and citation density [12]. The half-life (number of retrospective years required to find 50% of the cited references) is longer for a physiology journal than that for a physics journal. For some fields, *JCR*'s two-year based impact factors may or may not give as complete a picture as would a five- or ten-year period. Nevertheless, when journals are studied within disciplinary categories, the rankings based on 1-, 7- or 15-year impact factors do not differ significantly [6,7]. The citation density is the average number of references cited per source article. Citation density (R/S) is significantly lower for mathematics journals than for molecular biology journals. There is a widespread but mistaken belief that the size of the scientific community that a journal serves significantly affects the journal's impact factor. This assumption overlooks the fact that while most authors produce more citations, these must be shared by a larger number of cited articles. Most articles in most fields

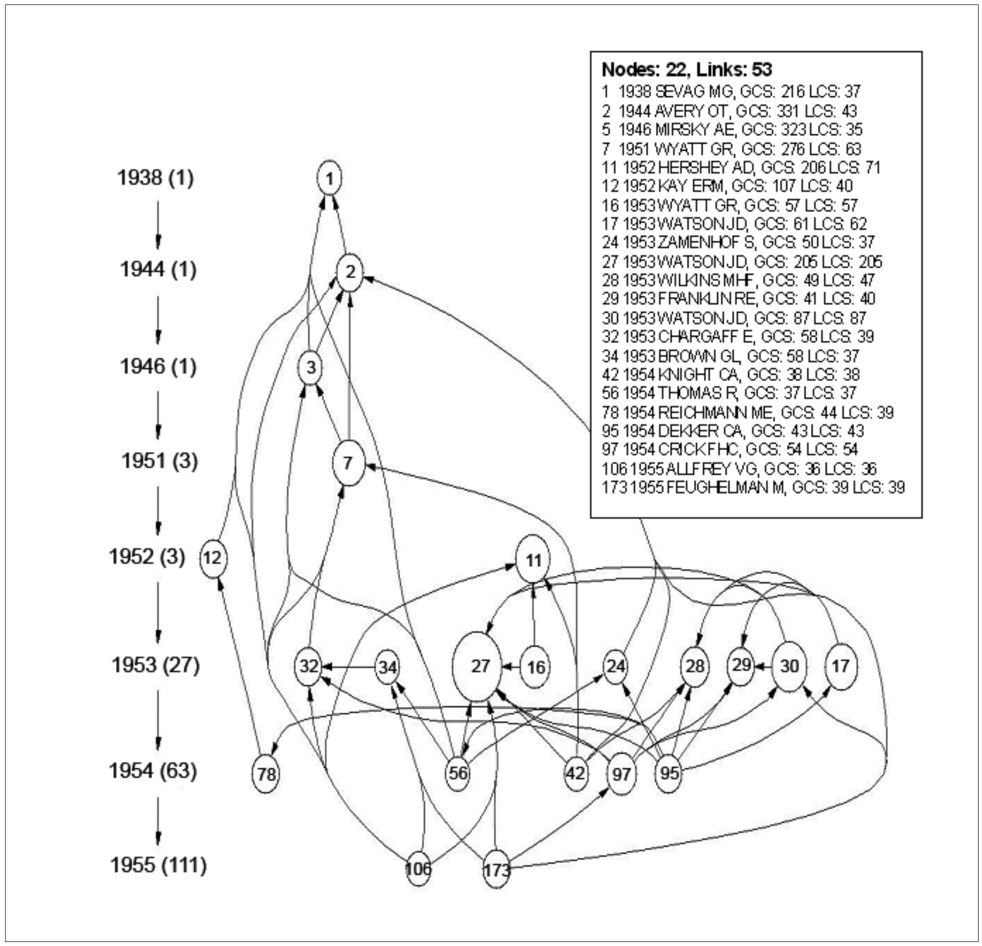

Fig. 1. Watson-Crick year-by-year historiograph (1938–1955). [From: Garfield E, Pudovkin AI, Istomin VI (2003) Mapping the output of topical searches in the *Web of Knowledge* and the case of Watson-Crick. *Information Technology and Libraries* 22:183-187]

are not well cited, whereas some articles in small fields may have unusual impact, especially when they have cross-disciplinary impact. The average number of citations per article and the immediacy of the citations—and not the number of authors or articles in the field—are the significant elements [5]. The size of the field, however, will generally increase the number of "super-cited" papers.

In addition to helping libraries decide which journals to purchase, journal impact factors are also used by authors to decide where to submit their articles. As a general rule, the journals with high impact factors include the most prestigious, although the perception of prestige is a murky subject. Librarians argue that the numerator in the impact-factor calculation is itself even more relevant. Bensman argues that this 2-year total citation count is a better guide to journal significance and cost-effectiveness than is the impact factor [1]. Journal impact can also be useful in comparing expected and actual citation frequency. Thus, when ISI prepares a personal citation report it provides data on the expected citation impact not only for a particular journal but also for a particular year, because impact factors can change year to year.

It is well known that there is a skewed distribution of citations in most fields: the 80/20 rule applies in that 20% of the articles may account for 80% of the citations. On the one hand, some editors would like to see impact factors calculated solely on the basis of their most-cited papers so that their otherwise low impact factors can be ignored. Others would like to see rankings by geographic area because of *SCI*'s alleged English language bias. Europhiles would like to be able to compare their journals by language or geographic groups especially in the social sciences and humanities. Other objections to impact factors are related to the system used in *JCR* to categorize journals. In a perfect system it ought to be possible to compare journals with an identical profile. But in fact, there are rarely two journals with identical semantic or bibliographic profiles. ISI's heuristic, somewhat subjective methods for categorizing journals are by no means perfect, even though their specialists do use citation analysis to support their decisions. There have been recent attempts to group journals more objectively, relying on two-way citational relationships between journals to reduce the subjective influence of journal titles [11], e.g., citation analysis proved that the

$$R_{1>2} = \frac{C_{1>2} \times 10^6}{Ref_1 \times Pap_2}$$

$$R_{1<2} = \frac{C_{1<2} \times 10^6}{Ref_2 \times Pap_1}$$

$$R_{coeff} = \sqrt{R_{1>2} \times R_{1<2}}$$

C = Citations

Ref_1 is the number of references cited in journal 1

Pap_2 is the number of papers published by journal

Ref_2 is the number of references cited in journal 2

Fig. 2. General formula for calculating citation relatedness between two journals and the relatedness coefficient expressing the average of the maximum and the minimum.

Journal of Experimental Medicine was a leading immunology journal. The coefficient of relatedness between two journals reflects how often a journal cites and is cited by each of the journals it is compared to, and it takes into account the sizes of the journals involved (papers published) as well as the number of times each journal cites the other (Fig. 2).

Many discrepancies with journal impact factors are eliminated altogether in another ISI database called the Journal Performance Indicators (JPI) [http://scientific.thomson.com /products/jpi]. This annual compilation now covers the period 1981 to the current year. Unlike *JCR*, this database links each source item to its own unique citations, making impact calculations more precise. Only citations to the substantive items are counted in the denominator, and it is possible to obtain cumulative impact measures covering longer time spans. Table 2 shows how the cumulated impact for *JAMA* articles published in 1999 was 84.5. In this year, *JAMA* published 1905 items of which 630 were letters, and 253 editorials; citations to these items were not included in the JPI calculation of impact. In spite of the alleged distortions introduced by counting citations to all "editorial" material in *SCI*, a recent report by González and Campanario at the University of Alcalá (Spain) demonstrates that the effect, if any, is quite minor [8].

The use of journal impact factors instead of actual article citation counts to evaluate individuals is a highly controversial issue. Granting and other policy agencies often wish to bypass the work involved in obtaining actual citation counts for individual articles and authors. Since recently published articles may not have had enough time to be cited, it is tempting to use the journal impact factor as a surrogate evaluation tool. Presumably the mere acceptance of the paper for publication by a high impact journal is an implied indicator of prestige. Typically, when the author's recent bibliography is examined, the impact factors of the journals involved are substituted in lieu of the actual citation count. This practice began about a decade ago, when administrators decided they would estimate the future impact of a recently published paper by incorporating the impact factor for the journal in which the paper is published. (For younger scientists, especially, many of the papers listed in their CV have been published often during the period used to calculate impact, and most of them will not be cited for a few years or more, depending upon the rate at which research on their topic progresses.) Thus, the impact factor is used to estimate the expected influence of individual papers, a rather dubious practice taking into account the aforementioned skewness observed for most journals.

Today, so-called "webometrics" are increasingly brought into play, though there is little evidence that this is any better than traditional citation analysis. Web "sitations" may occur a little earlier, but they are not the same as citations. Thus, one must distinguish between readership or downloading, and actual citation in new research papers. Nevertheless, some studies seem to indicate that web sitation is a harbinger of future citation.

The assumption that the impact of recent articles cannot be evaluated in *SCI* is not universally correct. While there may be several years delay on some topics, papers that achieve high impact are usually cited within months of publication and certainly within a year or so. This pattern of immediacy has enable *ISI* to identify "hot papers" in its bimonthly publication *Science Watch*. However, full confirmation of high impact is generally obtained two years later. *The Scientist* magazine waits up to two years to select "hot papers" for commentary by authors, yet most of these papers will eventually go on to become citation classics [http:// www.citationclassics.org].

Of the many conflicting opinions about impact factors, Hoeffel expressed the situation succinctly: "Impact factor is not a perfect tool to measure the quality of articles but there

Table 2. JPI data on *JAMA*. Citation impact (all items) in one year periods, 1981 to 2004 [from ISI Journal Performance Indicators file, 2004]

Rank	Year	Impact	Citations	Papers
1	1981	29.57	16,291	551
2	1982	35,53	20,358	573
3	1983	40.11	22,219	554
4	1984	35.26	21,791	618
5	1985	35.05	18,436	526
6	1986	48.76	24,576	504
7	1987	44.70	26,688	597
8	1988	48.40	30,009	620
9	1989	55.79	34,979	627
10	1990	54.83	35,968	656
11	1991	47.19	30,389	644
12	1992	58.48	34,389	588
13	1993	65.55	38,349	585
14	1994	70.54	39,148	555
15	1995	81.99	45,094	550
16	1996	60.16	32,908	547
17	1997	58.19	32,821	564
18	1998	75.20	37,372	497
19	1999	84.48[a]	31,257	370
20	2000	56.71	21,040	371
21	2001	49.98	18,842	377
22	2002	42.84	16,921	395
23	2003	19.09	7311	383
24	2004	3.34	1174	351

[a]Impact calculation:
31,257 / 370 = citations received from 1999 to 2004 / articles published in *JAMA* in 1999 = 84.5

is nothing better and it has the advantage of already being in existence and is, therefore, a good technique for scientific evaluation. Experience has shown that in each specialty the best journals are those in which it is most difficult to have an article accepted, and these are the journals that have a higher impact factor. Most of these journals existed long before the impact factor was devised. The use of impact factor as a measure of quality is widespread because it fits well with the opinion we have in each field of the best journals in our specialty. [9]"

Obviously, a better evaluation system would involve actually reading each article for quality, but even then difficulties of reconciling peer review judgments would arise. When it comes to evaluating faculty, most people do not have or care to take the time any more. Even if they did, their judgment would surely be tempered by observing the comments of those who have cited the work; this is known as citation context analysis. Fortunately, in the near future, full-text capabilities in the web will make this a more practical task to perform.

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