**The Journal of the Association for History and Computing,
Vol. I, No. 1., June 1998**

Historical Rankings of Science and Technology: A Citationist Perspective

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This article is adapted from a paper presented at The American Association for History and Computing annual meeting held in conjunction with the Second Annual Cincinnati Symposium on Computers and History April 24-25, 1998 at The University of Cincinnati, Cincinnati, Ohio.

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.01. Abstract (Back to Table of Contents)

Citation analysis is a well-established and widespread technique of assessing the influence and intellectual significance of published research over time. It provides the unique ability to pinpoint exactly when and where a particular paper or author was first cited or discussed. Historiographers of science and technology can use citation analysis to identify the most highly-cited individuals, institutions, and countries over time in terms of their individual or collective publishing records.

The limitations and shortcomings of citation analysis have been addressed by its critics and acknowledged by its proponents. Despite its flaws, no other methodology permits such precise identification of the individuals who have influenced thought, theory, and practice in the history of world science and technology.

.02. Introduction: The History of Computing(Back to Table of Contents)

The history of computers and computing technology is a living history. It is ongoing and in a continuous state of revision as archival documents are analyzed and critically examined and with the constant occurrence of new technological developments. It is interdisciplinary in nature, having its roots in ancient numerical systems, in mathematical and astronomical calculations, and closely interwoven with engineering, information and military science, physics and sociology.

In 1805 Joseph-Marie Jacquard developed a method of controlling the operation of a loom based on punched cards--an idea that was later used in early computers.[1] Charles Babbage, the "grandfather" of the computer age, conceived the idea of the first computer, the Analytical Engine, in 1832. He designed, but never completed, a working model of a machine which would read the punched cards conceived of by Jacquard.[2] In 1890 Herman Hollerith found a way to simplify handling census information from punched cards. In 1896 Hollerith founded Tabulating Machine Company--better known today as IBM. In 1925 Vannevar Bush developed the first analog computer which was designed to solve differential equations. In 1930, the first year sliced bread was introduced to the American marketplace! Bush completed the differential analyzer. In 1936, Konrad Zuse built a primitive form of digital computer. John V. Atanasoff and Clifford Berry completed the ABC or Atanasoff-Berry Computer in 1942. The ABC is considered the prototype for all later electronic computer designs.[3]

In 1944 the second electronic digital computer was completed by Howard Aiken and a team of IBM engineers. LISP, the first computer language, was developed in 1956. The keyboard for entering data was introduced in 1967 and the floppy disk appeared in 1970. The first personal computer was introduced in kit form in the United States in 1975. Two years later Apple presented the world the first personal computer in assembled form. Technology that is taken for granted today, the mouse and pulldown menus, did not appear until 1983. The fourteen years which have elapsed since the introduction of the Macintosh in 1984[4] have been years of unprecedented growth for the field of computer science and for all aspects of modern technology.

.03. Citation Analysis (Back to Table of Contents)

A citation is the acknowledgment that one document receives from another [5] and the practice of citation is a worldwide phenomenon.[6] Primary reasons for using citations include paying homage to intellectual pioneers, paying homage to one's intellectual peers, and identifying original publications in which an idea or concept was discussed.[7]

Citation analysis is a well-established and widespread technique of assessing the influence and intellectual significance of published research over time. This technique counts the number of times a published paper is cited in the professional literature. Individuals and institutions are ranked according to the impact their faculties exert within their individual research areas. Its use is predicated on the assumption that the more a publication is cited, the greater will be its quality and/or impact.[8]

Historiographers of science and technology use citation analysis to identify the most highly-cited individuals, institutions and countries in terms of their individual or collective publishing records. Citation analysis is important for studying the evolution of modern science because citations represent the cognitive links between ideas. Citation analysis provides the unique ability to pinpoint exactly when and where a particular paper or author was first cited or discussed. It also imparts an idea of the degree of receptivity of a particular idea at the time it was first presented.

.04. The Institute for Scientific Information (ISI) (Back to Table of Contents)

The Institute for Scientific Information (ISI) produces the three major citation indexes: The Science Citation Index (SCI), the Social Sciences Citation Index (SSCI), and the Arts & Humanities Citation Index (A&HCI). These are multidisciplinary indexes to the international journal literature. A citation index is a structured list of all the citations in a given collection of documents. The index is arranged so that the cited document is followed by the citing document. It is based

on the premise that an author's references to previously recorded information identify much of the earlier work that is pertinent to the present document.[9]

Ulrich's Directory of International Periodicals lists nearly 165,000 journals from 78,000 publishers. However, most of the significant information produced each year appears in only a small portion of them. This principle is referred to as Bradford's Law. It states, in essence, that an essential core of journals forms the literature basis for all disciplines and that most of the important papers are published in relatively few journals.[10] Recent citation analyses have shown that as few as 150 journals account for half of what is cited and about one quarter of what is published. A core of approximately 2,000 journals now account for about 85 percent of the world's published articles and 95 percent of the world's cited articles.[11] Only 40 percent of all published papers receive more than one citation.[12] About 25 percent of all published papers will never be cited and less than 17 percent are cited 17 or more times.[13]

ISI indexes over 8,000 journals--only a fraction of the world's output. For those journals indexed in depth by ISI, every paper published is indexed, along with all the references or citations made by the papers' authors to previous works. This includes editorials, notes, reviews, etc. Other journals are selectively indexed. Although the citation indexes continue to be published in print form, they are also available as online databases. These are much easier and faster to search than are the print indexes.

.05. The Web of Science (Back to Table of Contents)

The Web of Science, which was released in 1997, is a Web-browser interface that provides enhanced Web access to the ISI citation databases. There are two extraordinary features of the Web of Science. First, it permits the simultaneous searching of all three citation indexes. This feature is especially important for identifying the interdisciplinary impact of scholars and scientists. It also provides for the identification of all cited authors in the database--not just the first author, as is the case with the print and online versions of the citation indexes. ISI is currently the only database publisher in the world which indexes and links the cited references of each article.

SCI indexes 5,300 journals; SSCI covers 1,700 journals in depth and selectively indexes relevant articles from more than 3,300 other journals; and A&HCI covers over 1,150 journals and selectively indexes 5,000 others. Electronic journals are included. Taken together, ISI's citation indexes cover over 8,000 of the world's premier journals in all disciplines. The Web of Science is updated on a weekly basis.[14]

.06. Inclusion Criteria (Back to Table of Contents)

ISI's journal selection process has received criticism over time. In its defense, ISI adamantly states that "high journal publishing standards, especially timeliness, and English language bibliographic elements remain essential."[15]

In addition, ISI has included important "non-journal" material since 1977. These are published proceedings, symposia, monographic series, and multi-authored books, i.e., thematic collections of papers.[16] Conference proceedings, in particular, have always been a bibliographic nightmare for librarians who are responsible for identifying and locating this material for patrons. ISI has lessened this time-consuming reference ritual by including these papers but it has not alleviated the problem. For many years the Subject and Bibliographic Access to Science Materials was a standing committee in the Science and Technology Section of the American Library Association. This committees' diligence resulted in a useful publication, Guide to Searching the Bibliographic Utilities for Conference Proceedings.[17] This guide has been a boon to cataloging, interlibrary loan and reference librarians.

.07. Impact Factor (IF) (Back to Table of Contents)

The concept of the impact factor (IF) was developed by ISI in 1973. Impact factors are calculated by dividing the number of current-year citations (for example, 1997), to a journal's papers published in the previous two years (that is, 1996 and 1995) by the combined total of these papers.[18] The impact factor of a journal reflects the quality of a journal according to the global number of citations it receives within a given period of time. There is a [not surprising] consensus that as a rule the most-cited papers are more valuable than papers that are less-cited, or not cited at all.[19]

Citation indexing is unique as a retrieval system because it is a network of connections between authors citing the same papers during a given year. A surprising discovery about citation data has been the relatively low impact of articles published in most journals, including journals that seem almost universally accepted as preeminent. The number of journals that achieve an impact factor of two or more is small. There are only about 150 journals with impact factors greater than two, and fewer than 500 with impact factors greater than one![20]

Impact factors may well be distorted by a few highly-cited papers. For example, two small countries, Costa Rica and Peru, exceeded the world average in clinical medicine by their citation impact. However, these impact calculations were skewed by a few highly-cited papers by a few highly-cited authors.[21]

The achievements of scientists and social scientists can be documented by analyzing the citations to their works over time. Citation analysis identifies trends in science and technology. It identifies books and papers that are considered "classics," and it provides irrefutable evidence of the worldwide impact and

influence of individual scholars and scientists. For example, in 1975, Jean Piaget was identified as the most-cited psychologist in the world from a citation study of the publications of 5,597 psychologists. Piaget received 1,071 citations to his published works during this one-year period.[22]

.08. Selected Historiographers of Science (Back to Table of Contents)

1. George Alfred Leon Sarton

George Alfred Leon Sarton is the "father" of the history of science, having established the history of science as a discipline in its own right. His Introduction to the History of Science is a mammoth three-volume, 4,236-page work in which Sarton reviewed and cataloged the scientific and cultural contributions of every civilization from antiquity through the fourteenth century. He was the author of 15 other books and over 300 articles on this subject. Keeping in mind that most of Sarton's works were published well before 1955, the earliest date for which ISI's data are available, citation analyses of his works remain impressive. Between 1955-1984, volume I (1927) of his definitive work was cited 97 times; volume II (1931) 36 times; and volume III (1947) 26 times.[23]

2. Thomas S. Kuhn

Thomas S. Kuhn, best known for his 1962 revolutionary book, The Structure of Scientific Revolutions, was cited in publications indexed by ISI a total of 1,765 times between 1969-1977.[24] Of the top 250 most-cited authors in the Arts & Humanities Citation Index between 1976-1983, a total of 1,275 articles cited Kuhn 1,610 times.[25]

Indeed, Kuhn's views are still being cited, challenged and contradicted. At the International Workshop on the Historiography of Contemporary Science, Technology, and Medicine, held in Goteborg, Sweden in September, 1994, a range of alternative views emerged which acknowledged Kuhn's historiographical dictum. At the same time, contemporary historians of science were criticized for failing to apply successfully Kuhn's model to the historiography of science and technology.[26]

3. Robert K. Merton

Robert K. Merton is remembered as one of the preeminent sociologists of the twentieth century. Merton's name is almost synonymous with the term "sociology of science" and he is widely known beyond the parameters of his own discipline. Merton's Ph.D. dissertation on Science, Technology, and Society in 17th Century England was more than just another dissertation. It remains a strongly influential work in the sociology of science and has continued to exert significant impact on historians of science.[27] Merton's dissertation was just the beginning of a long and illustrious publishing record. In 1983, at the age of 73, he was the recipient of the prestigious $60,000 MacArthur Prize Fellow award.[28]

A comprehensive citation analysis of Merton's works illuminates his lasting influence upon diverse disciplines and reinforces his well-deserved reputation. There were 2,541 articles which cited Merton from 1970-1977. Two categories outside of sociology, the natural sciences and the social sciences other than sociology, account for 1,616 citing articles--64 percent of the total. When the 925 citations from sociology are excluded, the remaining 1,413 social science citations are over 50 times greater than the average and over 80 times greater if sociology is included. In the natural sciences, the 203 citations of his works is almost four times the average of 56.4 percent for a natural scientist. Thirteen percent of the number of articles citing Merton from 1961-1977 were from the relatively new field of information science; by 1977, nineteen percent of the number of articles citing Merton were from information science journals.[29]

The books Merton wrote and edited have been the major source of his influence. They accounted for 81 percent of his total citations from 1969-1977. His major work, Social Theory and Social Structure, received 1,418 citations during this period or 76 percent of his total citations.[30]

4. Derek John de Solla Price

Derek John de Solla Price remains best known for his work in scientometrics and the history of science, in which he received a second doctorate in 1954 from the University of Cambridge. His first doctorate was in experimental physics. Price was a significant force in the advancement of citation indexing. He is best known for his 1963 publication, Little Science, Big Science. Between 1963-1983, it had been cited 724 times in over 260 ISI-indexed journals in over 80 disciplines.[31]

Kuhn, Merton and Price, who wrote their most influential books in 1962, 1968 and 1963 respectively, have left their legacies on the history of science and technology through their exceptional ability to communicate their ideas. Their works remain today on the required reading lists of courses in colleges and universities all over the world and across all disciplines.

All of these historians have exerted a profound influence on the history of science and technology as evidenced by an analysis of who has cited them, where they have been cited and the number of times their works have received citations. Critics and skeptics of citation analysis may scoff at the numbers but it is worth noting that their works were all published well before ISI began to include "non-journal" literature and that citations to their works which appear in textbooks and single-authored books are not counted by ISI.

.09. World Impact of Scientific Papers (Back to Table of Contents)

Two major citation analyses of scientific papers from thirty nations were performed in 1991 and 1997. Published papers cited between 1981-1990 and from 1992-1996 were analyzed to determine their worldwide impact. In both studies, the same five

nations placed in the top five. In terms of citations per paper, Switzerland ranked first in both analyses. The United States, the Netherlands, Sweden and Denmark continued to dominate the top five spots in the 1997 analysis with only minor shifts in position.[32]

.10. World Impact of Computer Science and Mathematics Papers (Back to Table of Contents)

Switzerland's world share of published computer science papers between 1992-1996 was only 1.04 percent. However, its citations-per-paper average exceeded the world average by +47 percent. In fact, Switzerland exceeded the world average in all but two of twenty-one fields in the sciences and social sciences.[33]

Canadian universities were ranked by the number of papers and the average citations per paper, among those Canadian universities that published at least 50 papers in ISI-indexed journals of computer science between 1992 and 1996. In terms of numbers, the University of Waterloo published the most papers. In terms of citations, or impact per paper, Simon Fraser University was first.[34] The Canadian universities, however, were not compared against the world average.

World share citation statistics in computer science appeared in early 1998 for five small countries in three areas of the world. For the years 1992-1996, Austria's world share of computer science papers is currently 0.66 percent or -19 percent in its relative citation impact compared to the world; Finland contributed only 0.80 percent of the papers but its impact factor relative to the world was +21 percent; Italy contributed 3.91 percent of the world's share of computer science papers and its impact compared to the world was -6 percent; South Korea's contribution to the world's share of computer science papers was 1.43 percent with an overall world impact of -42 percent; and New Zealand contributed only 0.33 percent of the world's papers in computer science with a -23 percent relative world impact.[35]

The discipline of mathematics is an anomaly for the field of citation analysis. Mathematicians tend to cite older literature. It is not unusual for important mathematical works to be cited decades after publication.[36] The institutional affiliations of the 100 most-cited publications in pure mathematics during 1978-1979 were usurped by the University of Chicago which had nine of the most-cited mathematicians; Princeton University and Harvard University were tied with six mathematicians; the University of California accounted for five; and four mathematicians were from Yale University. Ten mathematicians were affiliated with seven French institutions and the Federal Republic of Germany had five institutions represented with a total of six authors.[37]

A recent study of the most prolific United States universities in mathematics from 1992-1996 provides a much different ranking than the previous one for cited mathematicians. Of the 53,807 papers entered into the ISI database, researchers at the University of Wisconsin, Madison accounted for 600 papers; the University of

California, Berkeley, 585; Rutgers University, 558; the University of Minnesota, 556; and Purdue University with 547 papers.[38]

.11. Conclusion (Back to Table of Contents)

Citation analysis is predicated largely upon citation frequency. Most papers have a limited lifetime citation expectancy. Sooner or later they are subject to "obliteration by incorporation." This means they are no longer cited because their substance has been absorbed by current knowledge.[39] In essence, this means that an assumption has been made that their content has become "common knowledge" and it is not necessary to continually cite and recite the obvious. Nevertheless, Freud, who died in 1939, received 1,426 citations to his works during 1975.[40] Garfield remarked that "obliteration...is one of the highest compliments the community of scientists can pay to their author".[41]

Papers of a controversial nature will continue to be cited longer. There are two additional factors which explain why some papers which we would expect to be highly-cited appear to be overlooked or ignored. The first is "bibliographic amnesia," defined as an unconscious plagiarism in which creative ideas expressed as new are actually unrecalled memories of another's idea. Delayed recognition of papers reporting significant research is the second factor. All scientists face a lack of explicit recognition in this era of "big science".[42] It is easy to get lost in the crowd.

Problems with citation analysis as a reliable evaluation instrument have been acknowledged throughout the literature. Chapman delineated 25 shortcomings, biases, deficiencies, and limitations of citation analysis. Among these are a bias against citations in non-English language publications and the exclusion of citations within books. Last, but not least, is human error in citation behavior.[43]

An American professor of information science, Linda C. Smith, stated that "citations are signposts left behind after information has been utilized".[44] Blaise Cronin, a British professor of library and information science, likewise defined citations as "frozen footprints in the landscape of scholarly achievement...which bear witness to the passage of ideas".[45] Whether citations are viewed as signposts or footprints, they serve as indicators of scholarly impact. Despite its flaws, citation analysis has demonstrated its reliability and usefulness as a tool for ranking and evaluating scholars and their publications. No other methodology permits such precise identification of the individuals who have influenced thought, theory, and practice in world science and technology.

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To cite this article: Lynn C. Hattendorf Westney, "Historical Rankings of Science and Technology: A Citationist Perspective," *The Journal of the Association of History and Computing*, vol 1, no 1 [http://mcel.pacificu.edu/history/jahc/Westney/Westney.htm] (June 1998).