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Impact factors, scientometrics and the history of citation-based research

Derek R. Smith

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Abstract Few contemporary inventions have influenced academic publishing as much as journal impact factors. On the other hand, debates and discussion on the potential limitations of, and appropriate uses for, journal performance indicators are almost as long as the history of the measures themselves. Given that scientometrics is often undertaken using bibliometric techniques, the history of the former is inextricably linked to the latter. As with any controversy it is difficult to separate an invention from its history, and for these reasons, the current article provides an overview of some key historical events of relevance to the impact factor. When he first proposed the concept over half a century ago, Garfield did not realise that impact factors would one day become the subject of such widespread controversy. As the current Special Issue of *Scientometrics* suggests, this debate continues today.

Keywords Impact factor · History · Bibliometrics · Scientometrics · Citation indexing

Introduction

In contemporary research and scholarly environments, few inventions have influenced medical publishing as much as journal impact factors (Brown 2007). Increasing attention is now being focussed on this particular aspect of journal performance, probably due to the intense competition of modern research environments, and the nature of the beast itself. Scientists now compete for publication space and recognition in scientific periodicals (Leydesdorff 2002), with journal articles themselves being optimised for consumption in 'human-readable aliquots' (Seringhaus and Gerstein 2007). On the other hand, from a more humanistic perspective, 'pecking order lists' have always held a certain fascination (Cawkell 1978), and its seems that 'everyone loves a number' (Brown 2007). Despite this fact, numbers are only numbers, with debates and discussion on the limitations of, and appropriate uses for, journal performance indicators being as long as the history of the

D. R. Smith (✉)
School of Health Sciences, Faculty of Health, University of Newcastle,
Ourimbah, NSW 2258, Australia
e-mail: derek.smith@newcastle.edu.au

measures themselves (Archambault and Larivière 2009; Glänzel 2009; Vanclay 2009). This may be why Eugene Garfield, inventor of the journal impact factor, once said that its existence is somewhat like nuclear energy—a mixed blessing. Certainly, when Garfield first proposed the concept over 50 years ago (Garfield 1955), he did not realise that impact factors would one day become the subject of such widespread controversy (Garfield 1999). As the current special issue of *Scientometrics* suggests, this debate continues today.

As with any controversy, it is difficult to separate an invention from history itself, and for these reasons, recounting some developmental milestones is clearly required. Given that, as a discipline, scientometrics is often undertaken using bibliometric techniques, the history of the former is thus inextricably linked to the latter. Modern scientometrics can trace its ancestry to some of the earliest precursors of modern bibliometrics—when humans first began creating indexes to printed works. Historical research suggests that the earliest indexes were predominantly compiled in the field of religion, primarily for the advancement of religion itself (Weinberg 1999). Alphabetical lists of words and phrases from the Hebrew Bible had been compiled by the 10th century, while various subject indexes were appearing in French literature by the 13th century (Weinberg 2000a). The first Hebrew citation index to a printed book is dated 1511 (Weinberg 1997), and interestingly, a common feature of early Hebrew and Latin dictionaries and indexes were a 'thanks to God' at the conclusion of the work—perhaps an equivalent of the modern day 'thank God it's over' (Weinberg 1999).

While medieval indexes from France certainly contained sophisticated structural and formatting features (Weinberg 2000b), the earliest citation analyses appear to have been undertaken in the legal field, with 'Tables of Cases Cited' being published at least since 1743, and a dedicated citation index book first appearing in 1860. In 1874 a count was made of chemistry publications, followed by two ambitious citation analyses of court decisions in 1894 and 1895 (Shapiro 1992). A few years prior to this, one of the more well-known precursors to the modern citation index appeared in Colorado Springs, Colorado—*Shepard's Citations*. In 1873 Frank Shepard began printing citations to Illinois Supreme Court cases for subscribers to paste into their report volumes, which eventually expanded to a nationwide system of bound books and legal supplements (Shapiro 1992). This made it possible for American lawyers to conveniently access previous court judgments and ascertain whether a legal precedent had since been overruled, reversed or otherwise distinguished in some way (Adair 1955).

By the early 20th century, an exponential growth in published literature had made it increasingly difficult to keep abreast of the latest scientific developments. Between 1884 and 1900 for example, there were over 380,000 author entries in the catalogue of scientific papers (Hulme 1925), and the actual number of scientific papers had doubled between 1901 and 1910 (Hutton 1961). While such numbers may seem reasonable in the modern information age where online databases abound and almost all knowledge is electronically cross-referenced, it is important to recognise that pioneering bibliometricians operated in a considerably more basic environment. Personal computers did not exist, and as a result, analytical tools available to the individual were comparatively primitive—meaning that bibliometric analyses were often limited to the counting of citations. Even so, various pioneering studies were still being undertaken during this period, with one of the earliest well-known examples (a statistical examination of the anatomy literature) being published in 1917 (Cole and Eales 1917). In 1926 Alfred Lotka (1880–1949) published his seminal study on publication frequency within *Chemical Abstracts* (1907–1916), reporting that the number of authors making n contributions is about $1/n^2$ of those making a single contribution (Lotka 1926). In 1927 Paul L.K. Gross and Gross examined reference frequency in

the *Journal of the American Chemical Society*, finding that although 99 periodicals had been referred to once, <10 had been referred to 15–20 times (Gross and Gross 1927).

Seven years later, in 1934, a seminal study of 'scatter' among important new contributions to knowledge was published by Samuel Bradford and E. Lancaster Jones of the Science Museum Library in London (Hutton 1961). In their study, the authors examined reference frequency in the journals, *Applied Geophysics* and *Lubrication*, concluding that scientific periodicals could be roughly divided into three groups: (1) a few very productive sources, (2) a larger number of moderate production, and finally, (3) an even larger proportion of constantly diminishing productivity (Bradford 1934). Although this concept eventually became known as Bradford's Law, as it closely resembles George Zipf's law of word frequency, it is often referred to as the Bradford-Zipf Distribution (Garfield 1980). George Kingsley Zipf (1902–1950) would publish his pioneering study of the principle of least effort in 1949, outlining the human tendency to communicate with words in the most efficient manner (Zipf 1949).

Although contemporary scholars have suggested that simple citation counting may fall somewhere between historiography and parlour game (Shapiro 1991), it is important that in the pre information-technology age when bibliometrics was being established as a discipline, there were realistically few alternatives. As a result, the 'Gross and Gross Method' (Gross and Gross 1927) of citation counting would inevitably be used for many years—all the while helping to elucidate some of the internal aspects of publishing culture and journal article distributions. As the discipline of information science evolved however, the inherent limitations of basic citation counting become more widely recognised, and subsequently, investigated. In 1944 for example, an analysis of physiology journals demonstrated that many previously held assumptions were actually incorrect, with Estelle Brodman revealing that no single journal was representative of its entire field and that not all journals could be weighted equally (Brodman 1944).

Science and technology also experienced a global rise to prominence during the mid 20th century, firstly as a means to fight the Second World War and secondly, due to the societal changes being felt as people looked beyond a world at war. Perhaps one of the most famous commentators was Vannevar Bush, then Director of the United States *Office of Scientific Research and Development*, who in 1945 published an article in *The Atlantic Monthly* proposing that mankind should strive to make all previous knowledge more accessible via increased connection between information trails (Bush 1945). At the same time, the need for an efficient indexing system had become increasingly apparent as the body of knowledge continued its expansion (Smith and Rivett 2009) to the point where scientists who deserved recognition could no longer be easily identified amidst the growing mass of scientific output (Garfield 1970).

The practical realities of this situation were not lost on a young information scientist named Eugene Garfield (b.1925) who, while working on the Welch Medical Indexing Project (which later evolved into the Index Medicus), had been alerted to the presence of *Shepard's Citations* by its former Vice president, William Adair. After being contacted by Adair to see if their concept might be applied to the sciences, Garfield visited a library to see Shepard's Citations for himself, and confirmed that it would indeed be well-suited to such a role (Smith 2007). Garfield subsequently encouraged Adair to publish his original idea (Adair 1955) and then wrote what is perhaps his most famous paper in the field of bibliometrics—the 1955 proposal of a citation index to help facilitate the dissemination and retrieval of scientific information (Garfield 1955). Garfield went on to found the *Institute for Scientific Information* (ISI) in the 1950s, with the inaugural *Science Citation Index*® (SCI) being published in the following decade (Garfield 2007a, b).

Given the large number of journals available, selecting the most important ones for inclusion within the SCI rapidly emerged as a monumental task. Early on it had, for example, become increasingly apparent that publication count alone might preclude some of the comparatively small periodicals even though they were of significant relevance to their particular field (Garfield 1999). For these reasons, the original author citation index was resorted into a journal citation index, thus creating the *Journal Impact Factor* which was first used in 1963 and had began appearing as a regular feature by 1976 (Garfield 1976). Detailed explanation on its calculation has been described elsewhere (Garfield 1986), although to recap briefly; a two year citation 'window' was chosen as Garfield and colleagues had previously found that one-quarter of all citations received in the current year were to material that was only 2–3 years old (Garfield 2007a, b). The outputs were calculated to three decimal places to help prevent too many titles receiving exactly the same score (Garfield 2006). The first year that impact factors were used is also known for another high water mark in scientometrics due to publication of the groundbreaking book *Little Science, Big Science* by Derek de Solla Price (1922–1983) (Price 1963). In his book, Price analysed patterns of scientific communication, finding that one-quarter of scientific authors are responsible for around three-quarters of all scientific papers—sometimes known as Price's law. He followed this up with a 1965 article in the journal *Science*, titled 'Networks of scientific papers' (Price 1965).

Fast forward to the 21st century—a 'golden age' of information technology, information science and knowledge retrieval—built on the tremendous increases in scientific production which made the emergence of scientometrics both necessary and possible (Price 1978). This has in turn, led to a situation where scientometrics is no longer just for librarians and a few associated researchers. We now operate in an era where the terms 'citation analysis', 'bibliometrics' and 'scientometrics' are becoming increasing well-known across virtually all scientific disciplines and where 'bibliometric awareness' has now become an essential criterion for research success (Smith and Hazelton 2011). In the modern climate of research competition and marketisation, we have seen bibliometric measures being increasingly used to evaluate research performance (Wiles et al. 2010). Governments and other funding bodies have increasingly sought to ensure that publically funded researchers are held accountable for the money spent and to disseminate their findings (Turale 2010). The *Research Assessment Exercise* in the United Kingdom and the *Excellence in Research for Australia* are two examples of how bibliometric evaluation can widely impact research planning and academic life. Similarly, these processes have also reminded academics and researchers of the importance of 'impact' when evaluating their own performance—at least part of which is now being evaluated via bibliometric indicators such as citation counts and journal impact factors. However, this was not always the case. While bibliometrics and scientometrics may have been evolving over the past few 100 years, as this paper has already described, familiarity with and uptake of the terms we use in everyday practice has not been as rapid outside the field.

Edward Wyndham Hulme is often credited as a developmental figure in the scientometrics nomenclature—having first used the term *statistical biography* during two lectures at the University of Cambridge in 1922, both of which were published as a book in the following year (Hulme 1923). It is equally worth remembering that Hulme was an important developmental figure in his own right, having joined the Patent Office in 1881, being promoted to librarian in 1894, and eventually remaining in the position until his retirement in 1919. He is perhaps most well-known for organizing the Panizzi Club in 1914 (A.W.P. 1914), and being founder and Editor of *The Subject Index to Periodicals* in 1915 (Gravell 1954). In 1969 Alan Pritchard proposed the term 'bibliometrics' (Pritchard 1969),

and while Derek de Solla Price has often been referred to as the 'father' of scientometrics (Garfield 2007a, b), he did not necessarily invent the name. That honour goes to the Russian mathematician and philosopher, Vasily Nalimov, whose classic 1973 Russian monograph bears the title *Naukometriya*—or 'Scientometrics' in English (Thompson 1993). Much has been written about Vasily Vasilyevich Nalimov (1910–1997), including a dedicated memorial issue in the journal *Scientometrics* (Braun 2001a). Indeed it was foundation of this journal in 1978 that lead to the term scientometrics being much more widely known (Garfield 2007a, b). Conferences were also important in dissemination of the field, as well as its name. This year, 2012, marks the 25th anniversary of the first *International Society for Scientometrics and Informetrics* (ISSI) conference which was held in Belgium in 1987.

It is not surprising that as bibliometrics and scientometrics grew in stature, scholars began to take an increasing interest in the details and mathematical foundations on which many of the calculations are based. As such, it is inevitable that the advent of bibliometric indicators themselves was always destined to attract criticism, and invite improvements and suggestions of alternatives. From an individual perspective, the 'broad brush' approach of bestowing credit on an author based on the relative prestige of journals in which they publish research findings has often attracted criticism. It has been suggested that measures of citation quality are only of value when they can be reliably assigned to individual authors (Lehmann et al. 2006), and as a result, the drive to more accurately quantify an individual's scientific research output has led to the development of various, individually assessed, bibliometric measures. Perhaps the most famous is the *h-index* proposed by Hirsch in 2005, and which is now being increasingly utilised (Hirsch 2005). A little less well-known indicator was Taber's proposal for a *c-index*—where *c* is the number of papers written by a particular author that have been cited more than once by other research groups in the most recent calendar year (Taber 2005). From a 'pecking order' perspective, various field-specific ranking methods and strategies for identifying 'core' journals have also been proposed. A few examples of these are worth recounting.

The *Ergonomics Journal List* (EJL) is one such case in point, being first proposed in 2004 to rank periodicals in the field of ergonomics and human factors (Dul and Karwowski 2004), and later revised in 2005 to include correlations between the EJL and peer evaluations of journal quality (Dul et al. 2005). In 2009 a ranking method known as the *Journal Evaluation Tool* was developed for nursing and midwifery periodicals, which utilises literature reviews, Delphi surveys and focus groups to sort journals into quality bands (Crookes et al. 2009). In 2010 a ranking tool was developed for environmental and occupational health periodicals—one of the first to utilise both the journal impact factor and the *SCImago Journal Rank* (SJR) within its calculations, as well as citation counts from the *Web of Science* and *Scopus* (Smith 2010a, b). This method also takes into account a journal's age, one of the first indicators to do so, in recognition of an 'older' journal's comparatively greater contribution to the dissemination of scientific research over time (Smith 2010a, b). The concept of journal 'age' as an inclusion criteria for core lists is not without precedent (Takahashi et al. 1996), and given that the history of a particular field and its journals are inextricably interwoven (Smith 2009), it would seem prudent to consider 'survivability' as an esteem measure in this regard. Similarly, given the cross-correlations that are known to occur across the different journal citation indices (Elkins et al. 2010), it would seem appropriate to use multiple databases when conducting 'rank' assessments in a particular field.

Another issue when rating journals is that of relative position, and the fact that high ranking journals often maintain their relative position within the 'pack' over time.

Although the term 'success breeds success' is well-known from a general perspective, it can also be applied to bibliometrics, and by extension, impact factors. One phenomenon elucidated early on was that an author who has published many scientific articles is more likely to publish again when compared to someone who has published little—'a millionaire gets extra income faster and easier than a beggar' (Price 1976), as Price once said. By extension, this would suggest that journals with high impact factors are more likely to keep them—a phenomenon that has been demonstrated with longitudinal analysis of bibliometric data in at least two fields—occupational medicine (Smith 2008) and nursing (Smith 2010c). On the other hand, impact factors are believed to be increasing in a general sense (Ogden and Bartley 2008; Althouse et al. 2009), while the ranking of top level journals appears to be less stable in smaller fields, such as ergonomics (Smith 2010d). How this might work in detail has been studied by various authors. An investigation of the finance literature (Chung and Cox 1990) for example, examined Lotka's Law of scientific productivity (Lotka 1926), finding that that while the finance literature conforms well to the inverse square law, the aforementioned 'success breeds success' phenomenon appears to be more common in higher quality publications.

Longitudinal examination of bibliometric trends, such as citations and impact factors, has also contributed to a deeper understanding of scientometrics in other ways. At the broadest level, its usefulness in providing research performance measures in an increasingly competitive and 'marketised' era has been documented (Wiles et al. 2010). Other applications have also emerged, such as helping to chart related historical trends in clinical practice and research norms (Mogil et al. 2009), as well as illuminating a particular profession's evolution—especially its evolving knowledge base (Coronado et al. 2011). Performance indicators such as impact factors, as well as more 'raw' forms of data such as citation counts, all comprise part of this story. Historical examination of impact factors, citation counts and other indicators also helps elucidate additional aspects of publication and scientific history (Smith 2008). This appears to have been recognised by Garfield early on—given that perhaps the most comprehensive body of historical bibliometric research was undertaken, published and collated by Garfield himself (Garfield 2012).

While gaining an impact factor may afford in itself some perceived degree of 'certification', it is a journal's inclusion on the bibliometric *databases* that probably affords the greatest benefit. The ability to undertake bibliometric analysis when a particular journal is added to a database opens, at once, a hitherto impossible suite of investigations, examinations and analyses. Despite this fact, the newly emerging field of '*historical bibliometrics*' as I like to call it, still represents a relatively under-researched area—albeit one awash with potentially 'ripe pickings'. Early-career researchers and experienced scholars alike would do well to further elucidate this relatively understudied aspect of information science.

For all of the discussion, analysis and debate we may have, it is important to remember that pecking order lists are not necessarily the be-all-and-end-all for those who actually conduct and ultimately publish articles upon which the aforementioned calculations are based. While journal citation rates can be a sweet and sour dish (Braun and Glanzel 1995), so too, scientometrics can be a double-edged sword. Examination and evaluation of research with bibliometric measures alone is not without its downfalls, of course, with at least one recent investigation suggesting that management policies which focus on bibliometric indicators may have actually led to increased competition between researchers, rather than cooperation (Ketefian and Dai 2010). This is hardly surprising though, as argument and debate is inevitable in scientometrics. Inventor of the term, Vassily Nalimov, once said the discipline itself can be an expressly 'unhappy' one—particularly when its data is used to for the evaluation of individuals, and journals (Braun 2001b). In many ways

we have now reached that point—although it is important to recognise that the turning point of a journey is not necessarily the end of the road.

Given that the literature of scientometrics is both comprehended by some and misunderstood by many (Hood and Wilson 2001), discussion and debate has always been the lifeblood of academic thought. Such robust exchange must continue. History has seen journal impact factors rise to become one of the most popular bibliometric products (Glänzel and Moed 2002), and are almost certainly one of the most 'argued about' topics in our field today. The current special issue of *Scientometrics* suggests that this debate will probably continue for a long time to come. Regardless of whether one considers bibliometric indicators such as impact factors to be an 'outdated artefact' (Vanclay 2011) in need of an overhaul (Rousseau 2012), it is important to keep focussed on the fundamental goal of scientometrics. Certainly Nalimov recognised early on the extraordinary opportunities that our field offers, having suggested that scientometrics can open the way for understanding the development of science as an informational process (Bonitz 2001). In 2012, on the 25th Anniversary of the inaugural ISSI conference, perhaps it's time to open the doors a little wider.

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