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EDITORIAL

Rankings and Records

Cricket and indeed many sports are dominated by statistics. Connoiseurs of the game are quick to cite facts and figures. In today's world, one cannot escape displays of ever-changing rankings of teams and players, based on precise, constantly updated facts. A few weeks ago, the Australian cricket captain, Steve Waugh made yet another century, crossing the legendary Don Bradman's haul, to become his country's record holder for Test hundreds. When asked how he felt while overhauling Bradman, Waugh laconically noted that he had batted considerably more times than his illustrious predecessor. Waugh's message was clear; averages may be more significant than raw numbers. Ever since computers revolutionized the methods of data storage, handling and retrieval, science too has been gripped by the infection of making quantitative comparisons. For a long time after its inception, the weapon of the Science Citation Index (*SCI*) found little application in India. The database was expensive, relatively unavailable and few appreciated its value. Times have changed. The Institute of Scientific Information's (ISI) Web of Science, a beguilingly named network of science databases and connections to the literature, is now more widely accessible from several major institutions in India. Amateur analysts now abound. Total counts of papers from institutions and individuals, indexed in the *SCI*, can be easily computed. Journal impact factors can be used to provide a seductively misleading measure of average quality. With a little more work, citations per paper can be counted, providing yet another parameter for ranking individuals, departments, institutions, organizations and even nations. There is a vicarious pleasure in being able to compare oneself, apparently objectively and quantitatively, with one's colleagues; those on top clearly more comfortable with the derived rankings. In India, where the number of ISI indexed papers is relatively small and the number of citations they accrue is modest, the dangers of misrepresenting and misinterpreting publication statistics is great. Despite these misgivings, the power of the ISI databases for assessing published science cannot be underestimated.

The problem of measuring the impact of science is immeasurably complex. For an economic analyst, the measurement of returns of investment on science may appear hard to quantitate. Bibliometrics, which to the unsophisticated is the field of counting papers and citations, provides one measure of assessment; albeit, largely limited to the area of published, academic science. Some years ago at a colloquium organized by the US National Academy of Sciences entitled 'Science, Technology and Economy', J. Adams and Z. Griliches presented an interesting bibliometric analysis of US science, restricting their attention to five fields: biology, chemistry, physics, medicine and mathematics covering the period 1981–1993. They counted papers and citations, using the citations per paper with five-year windows. Their conclusion, which the authors highlight as 'inconclusive' are interesting: 'From the numbers we have, one could conclude that United States academic science has been facing diminishing returns in terms of papers produced per R&D dollar, both because of the rising cost of achieving new results within specific scientific fields and because of rising competition due to the overall size of the scientific enterprise both within the United States and worldwide, impinging on a relatively slow growing publication outlets universe. In terms of total citations achieved per R&D dollar, the picture is somewhat brighter, indicating a rising quality of United States science in the face of such difficulties, though this interpretation is clouded by the question whether the actual science is better or is it just being evaluated on a larger and changing stage (the growing number of journals and papers in the world as a whole and changing citation practices)' (*Proc. Natl. Acad. Sci. USA*, 1996, **93**, 12664). Any analysis done today in India may also show mixed trends; interpretations must be made circumspectly and cautiously.

There are many situations where the cataloguing of the most highly cited papers provide fascinating glimpses of the growth of a discipline and its connections with sister sciences. The *Journal of the American Chemical Society* (*JACS*), the flagship publication of an organization which often bills itself as the 'world's largest scientific society , has entered its 125th year of publication. A century and a quarter is long enough for a meaningful retrospective. In an editorial filled with facts, the journal's editor, Peter J. Stang provides a marvelous glimpse of the growth of modern chemistry, as mirrored on the pages of *JACS* (Stang, P. J., *J. Am. Chem. Soc.*, 2003, **125**, 1–8). Volume 1 of *JACS* appeared in 1879, at a time when science was dominated by European laboratories and journals. From a mod-

est beginning, 621 pages in Volume 1, the journal has swollen to over 15,000 pages in Volume 124, a growth which will be paralled by comparable journals in other fields of science, where research activity has increased spectacularly over the last century. Biochemists (many who are now transformed into molecular biologists and at times, even biotechnologists) will note the growth of the *Journal of Biological Chemistry* (*JBC*, founded 1905), over the last nearly hundred years. Indeed, chemistry dominated the pages of *JBC* for several decades; its transformation occurring only in the wake of the revolution in molecular genetics and cell biology. Physicists will, of course, correlate the growth of their discipline with the number of papers, pages and subsections in *Physical Review*. In his essay, Stang marks the *JACS* anniversary by listing (and ranking by total citation count) the top 125 papers that have appeared in *JACS*. Few modern chemists can confidently claim that they could have predicted the outcome. Leading the list by a very big margin is the famous paper by H. Lineweaver and D. Burk on 'The Determination of Enzyme Dissociation Constants' (*J. Am. Chem. Soc.*, 1934, **56**, 658). Cricket and chemistry aficionados will note fondly that its year of publication corresponds with one of Bradman's triumphal English campaigns. Lineweaver and Burk, who are now immortalized in a plot that bears their name have thus far accumulated 10,638 citations, placing them far ahead of the competition. In second place is the paper by M. J. S. Dewar and his colleagues; 'AM1: A New General Purpose Quantum Mechanical Molecular Model' (*J. Am. Chem. Soc.*, 1985, **107**, 3902) which has garnered 7623 citations. Will Dewar *et al.* overtake Lineweaver–Burk in the future? Citation frequencies and half-lives will determine the outcome, but in the race for citation stardom scientists, unlike cricketers, continue to have their hats in the ring long after they have retired from the action. Stang's list is interesting and revealing; there are only 5 papers in *JACS* which have accumulated over 4000 citations, with the only representative of synthetic chemistry being R. B. Merrifield's 'Solid Phase Peptide Synthesis. 1. The Synthesis of a Tetrapeptide' (*J. Am. Chem. Soc.*, 1963, **85**, 2149). Curiously, a cursory analysis of the top 25 papers suggests that about half of chemistry's statistical stars are theoretical in nature, while a quarter might be classified as biochemistry. Indeed a careful perusal of the *JACS* 'stars list' immediately identifies the techniques which have had considerable impact on studies of molecules; most prominently nuclear magnetic resonance (NMR). Nobel laureates are well represented in the top 125; R. B. Merrifield, J. A. Pople, L. Onsager, C. J. Pedersen, P. D. Boyer, R. S. Mulliken, E. J. Corey, H. C. Brown, I. Langmuir, R. R. Ernst, K. B. Sharpless, L. Pauling, V. du Vigneaud, R. B. Woodward, R. Hoffmann, P. J. Flory, D. J. Cram and M. Calvin find a place. While *JACS* may not have been the only outlet for 125 years of chemistry, Stang's list provides many insights into the development of a central area of science.

In considering rankings of papers, journals, scientists, institutions and nations it is important to remember that 'there is plenty of room at the top'. It is not difficult to identify truly important and useful papers by citation counts. It may be far more difficult to make distinctions at the bottom of the pyramid of science, where the base is very broad. How many citations must a paper gather before a reasonable degree of significance is attached. One hundred (a century in cricket, too) appears to be a good choice; Stang notes that the author having the most publications in *JACS* with 100 or more citations is E. J. Corey, a finding that should gladden the hearts of synthetic chemists. Records and lists of citations are now regularly compiled by ISI's *ScienceWatch*, investing science with some of the excitement and glamour associated with sporting events and beauty contests (cf. *ScienceWatch*, 1997, **8**, 2, for a list of the most highly cited authors in the Physical Sciences 1990–96).

The ranking of journals by impact factors has also transformed the way scientists choose journals as a vehicle to report their results; the higher impact journals being flooded with submissions. In most local assessments, a poorly cited paper in a high impact journal scores over a well-cited paper in a low impact journal. Most senior (and sadly enough, many younger) scientists in India appear to be innocent of the entire area of bibliometric analysis of science, resulting in the creation of an environment where misconceptions abound. The practice of assessing scientists in committees by quickly computing 'average impact factors' is pernicious; the ready acceptance of this parameter by many science administrators must be vigourously resisted. But, it is not only the average scientist who worries that his or her work may pass unnoticed, another drop in the expanding vastness of the scientific literature. Journal editors are also increasingly self-conscious about impact factors; sometimes pandering to transient fashions in science in order to enhance the immediacy of their journals. A thoughtful commentary in the *Journal of Bacteriology*, celebrating the centennial of the American Society of Microbiology, outlined an editorial life 'beyond the impact factor'. The essay noted that the impact factor assesses only a fraction of a journal's impact on the development of a scientific discipline' (Walker, G. C., *J. Bacteriol.*, 1999, **181**, 1). In the specific case illustrated, only 17% of the citations to the journal were used in the impact factor calculation, which is a good measure of current interest in an area. But, for conservative, professional journals a long range impact assessment may provide a better guide. In assessing journals and scientists, the dangers of cross-disciplinary comparisons are self-evident. Publication and citation practices vary and specific yardsticks are needed, before jumping to judgemental conclusions.

There is an element of compelling human interest in generating rankings of individuals and institutions. We might only do well to remember that for the Bradmans, Waughs, Tendulkars and Gavaskars to emerge there must be a very large number of people enthusiastically playing the game.

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