Jointly published by Akadémiai Kiadó, Budapest *Scientometrics, Vol. 69, No. 1 (2006) 000–000*
and Springer, Dordrecht

Opinion paper

The scientists pyramid

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In this short paper I propose a combination of qualitative and quantitative criteria to classify the quality, talent and creative thinking of the scientists of the "hard", medical and biological sciences. The rationale for the proposed classification is to focus on the impact and overall achievements of each individual scientist and on how he is perceived by his own community. This new method is probably more complete than any other form of traditional judgment of a scientist's achievements and reputation, and may be useful for funding agencies, editors of scientific journals, science academies, universities, and research laboratories.

Introduction

Scientists are often judged in several clubby and unreliable ways and the used methods have not yet been widely accepted and normalized. A curious fact, for instance, is that Lev Landau once proposed a logarithmic ranking for physicists. Einstein he placed in class 0.5, Dirac and Heisenberg in class 1.0, and Landau himself, modestly, in class 2.5![1]

Among several criteria, the number of citations a scientist's papers gain in other scientists' papers provides a quantitative ranking tool, which despite its several

Received April 3, 2006

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0138–9130/US $ 20.00

difficulties, is dominating the struggle for grants, tenure, promotion and reputation. In addition to the cumulative number of citations, sophisticated citation parameters have been offered. For instance, recently, Hirsch proposed the *h*-index[2] based on the highest number of papers a scientist has that have each received at least that number of citations. Thus, someone with an *h*-index of 20 has written 20 papers that have each had at least 20 citations. This is probably fairer than alternative measures based on publication because counting total papers could also reward those with many mediocre publications, whereas just counting highest-ranked papers may not recognize a large and consistent body of research. Hirsch suggests that, for *physicists*, after 20 years in research, an *h* of 20 is a sign of success, and one of 40 indicates "outstanding scientists likely to be found only at the major research laboratories". For instance, several Nobel laureates have *h*-indexes from about 70 to 90.

However, as for the other indexes, there are a number of difficulties with the *h*-index. Just to exemplify, a cursory test with the Web of Science of four randomly chosen theoretical physicists, the only requisite being that they should have similar *h*-indexes, reveals the following figures (Table 1):

Table 1. Scientometric data for active theoretical physicists

	No. ISI articles	Citations	Citations/paper	*h*
Physicist 1	41 since 1979	700	17	12
Physicist 2	51 since 1984	560	11	11
Physicist 3	67 since 1976	403	06	11
Physicist 4	76 since 1976	280	04	10

Table 1 shows that the significantly higher number of citations and average number of citations per paper of physicist 1 is *not* reflected by the very similar *h*-indexes of these four researchers. Hence, one may wonder which parameter is best: the cumulative number of citations, the average number of citations/paper or the *h*-index? Additionally, different disciplines have widely different citation patterns, so each field would need different thresholds. Extremely prolific biologists can achieve *h* values of up to about 200,[2] while highly experienced, renowned, creative mathematicians and engineers, for instance, only achieve maximum *h*-indexes an order of magnitude less. It is quite clear that all quantitative criteria have some drawbacks. Hence, a more holistic way to evaluate the quality, talent and reputation of a scientist is urgently needed.

For three years (1993–1995) I acted as consultant for the materials science and engineering committee of CNPq, the National Council for Scientific and Technological Development, Brazil: http://www.cnpq.br/english/aboutcnpq/index.htm a government agency. One of our greatest difficulties in judging research proposals was to assess the experience and quality of the principal investigators (PI). During that period, we evaluated the productivity of PIs based on traditional *quantitative* indicators such as the number of papers published, number of PhD theses directed, etc. For researchers in a given field of knowledge, a comparison of these quantitative criteria seemed appropriate at the time. More recently, however, that same committee as well as other engineering and science committees have enhanced the sophistication of these quantitative indicators, for instance, by multiplying the number of articles published by the impact factor of each journal, and then, sometimes, dividing by the number of co-authors, by taking into account the number of MSc dissertations supervised (in addition to PhD theses), the number of papers presented at national and international conferences, and, since Brazilians were slowly becoming more aware of patents (see for instance Refs 3,4) by including the number of patents granted to each researcher in his/her evaluation. However, in a recent news brief,[5] Dr. Erney Camargo, the president of CNPq, stated that, despite several improvements in recent years, their difficulties in evaluating scientists performance still persists!

For ten years (November 1994 to January 2005), I also served on the scientific board of FAPESP, The State of São Paulo Research Foundation, Brazil: http://www.fapesp.br/english/index.php. However, at FAPESP we dealt not only with materials science and engineering, but with all the distinct areas of the "hard" sciences (physics, chemistry, mathematics, computer science, astronomy and geological sciences – each of these fields having several internal subdivisions) and all the different engineering programs. This enormous variety of fields and endeavors made it very difficult to compare the individual achievements and experience of researchers working in all these different areas of knowledge.

This experience prompted me to attempt to devise a more comprehensive way to evaluate researchers' performance, including relevant quantitative and mainly *qualitative* indicators. Of particular importance in this context was a paper authored by De Meis et al.,[6] which described a correlation between scientometric data and peer ranking. That study was carried out with 40 Brazilian researchers responsible for 54% of all the papers published by Brazilians in the fields of biochemistry and molecular biology over a 10-year period. Scientists were rated by their peers on a numerical scale. Evaluations were based on both formal and informal professional contacts over a number of years, within this particular scientific community. Scores awarded independently by the 19 raters showed remarkable agreement (even for self-evaluation), and there was evidence of a strong sense of hierarchy. There was also a strong correlation between this ranking and scientometric data (number of publications, citations, and impact factors). Their findings clearly indicate that the scientific community has a highly accurate sense of its peers.

In this short communication I propose a combination of mostly qualitative (plus some quantitative) criteria to classify the quality, talent and creative thinking of the scientists of the "hard", medical and biological sciences. The rationale for the proposed classification is to focus on the impact and overall achievements of each individual scientist and on how he is perceived by his own community rather than rely primarily on the number of scientific papers he has published, the number of citations, the number of PhD students he has supervised, and other traditional criteria.

The new method

As a result of considerable reading and pondering over this particular issue, but mostly based on my empirical experience at FAPESP (I analyzed about 100 projects per week during 48 weeks per year over 10 years = 48,000 proposals), I came up with a criterion (Table 2) to classify active scientists working in all the aforementioned hard sciences into four categories. Obviously, this table would not directly apply to the human and social sciences. However, Meneghini,[7] a scientometrics expert who held a similar position at FAPESP for the medical and biological sciences, confirmed that this table would also usefully distinguish scientists working in the fields of medicine, biochemistry and biology. It can thus cover an impressively broad field.

Unfortunately, statistics are not yet available, of course, on the percentage of researchers belonging to each of these four classes, but, to a first approximation, it is safe to assume that the frequency distribution resembles a pyramid, with very few at the top. It is obviously quite hard to meet all the requirements listed in Table 2 to be classified at the top of the pyramid, and only a small percentage of experienced researchers, typically with more than 20 years of professional experience, reach that category. To be ranked in a given category, I arbitrarily propose that a given scientist must satisfy at least 9 criteria (about 80%) of the 11 listed. The majority of active researchers are probably allocated to classes C and B. While it is perfectly normal that young researchers should initially belong to class C, the most active, motivated and creative should move to class B within a few years of independent research, e.g., soon after completion of a productive post-doctoral period.

Discussion and conclusions

Obviously scientists of agricultural, underdeveloped and emerging (or developing) countries do not have equivalent scientific equipment and research infrastructure, e.g., state-of-art computer facilities, plentiful libraries, etc., at their disposal and live in a comparatively poorer environment, i.e. do not have the same abundance of international level congresses and symposia, etc., and they also encounter more difficulties in raising sufficient funding than do their peers in the most advanced economies. Therefore, the first have fewer chances of reaching the top levels, but this fact does not invalidate the criteria of Table 1.

Table 2. Qualitative and quantitative characteristics of four categories of researchers of the "hard", medical, and biological sciences

Top	-frequently publish breakthrough articles in top ranking scientific journals (e.g., Nature, Science, Cell, New England J. Medicine, Phys. Rev. Letters, etc.) And as a result of the quality and impact of their research: -receive some of the most important prizes and awards in their respective fields -work in or direct world class laboratories or institutions -raise abundant research funds -are members of prestigious national and international science academies -are members of the editorial boards of archival journals -frequently give opening and plenary talks at the most important congresses in their specialties -have been session chairs of many important congresses and symposia -are frequently cited in the media (Google or Altavista search shows thousands of citations) -are cited in most textbooks of their specific research field -have received thousands of citations in ISI journals
Class A	-frequently publish in archival journals and -receive some prizes and awards in their specialties -work in or direct well-known laboratories -raise significant amounts of research money -are members of national academies of science -are members of editorial boards of prestigious journals -give invited talks in important international congresses -have been session chairs of several international congresses and symposia -Google or Altavista search shows positive citations in 500 or more web sites -are cited in several textbooks of their specific research field -have over 500 citations in ISI journals
Class B	-publish in journals of their specific field and -sometimes receive national prizes -work in good laboratories -raise enough research money -are not members of academies of science -are members of editorial boards of local scientific journals -give contributed talks/ posters in international congresses -have been session chairs of some congresses and symposia, mostly national -Google or Altavista search shows positive citations in about 50-300 web sites -are rarely cited in textbooks -have a few hundred citations in ISI journals
Class C	-publish mostly in local journals and conference proceedings in their specific fields -do not receive any prize or distinction -work in incipient or unknown laboratories and institutions -are not members of academies of science -are not members of editorial boards of scientific journals -have great difficulty to raise research money -present papers mostly at national conferences -have never or only rarely been session chairs of congresses and symposia -Google or Altavista search show very few positive citations in the web -are not cited in any textbook -have only a few or no citations in ISI journals

The evaluation of scientists by this new approach may require considerable time and experience. But funding agencies and any other organization interested in such ranking could instruct scientists to prepare their curricula in an appropriate format to include the information required by Table 2. And most importantly, Internet publication now permits an even greater step forward. When all information and scientific papers are stored in, and accessed from one vast computer database, it will be easy to extract all the necessary information about a person at any moment. This type of search, however, must be carefully executed to exclude repetitions and homonyms. While the new method here proposed is more elaborate than earlier approaches, it deserves to be applied for a while and then reviewed for possible adjustment.

An anonymous reviewer pointed out a potential drawback of Table 2. As several criteria listed in Table 2 are qualitative, they may be perceived as being subjective, but that in fact is not the case. It is well-known that researchers of different areas (and sub-areas) of knowledge use widely different journals and strategies. For instance, in general, engineers and mathematicians publish much less that physicists or biochemists. If I take, as an example, my own speciality – materials science with emphasis in glasses – I could easily quantify criteria that may, at first glance, be seen as subjective in Table 2. The anonymous referee specifically asked:

i) What is the meaning of "awards in their specialities". In the field on glass, for example, the Zachariasen Award given by the *Journal of Non-Crystalline Solids*, the Morey Award by the American Ceramic Society; the Otto-Schott Research Prize by the Carl Zeiss Foundation, the Gottardi Prize by the International Commission on Glass are among the most prestigious. Obviously each speciality has its own awards.

ii) What is the meaning of "frequently publish in archival journals". Archival journals are periodicals of long tradition, that use two or more referees to analyze each article, and that are regularly consulted by active researchers in their particular fields. In my own speciality, I can safely say that any researcher that regularly published more than 3-4 papers per year in the last 15-20 years in the *Journal of Non-Crystalline Solids*, or *Journal of the American Ceramic Society*, or in solid state physics and chemistry journals, such as *Physical Review B,* or in the *Journal of Chemical Physics,* is in good shape (there are several other archival journals in this particular speciality).

Obviously other journals are used by researchers of other specialities (and sub-areas) of knowledge. Any experienced researcher working in any particular field can easily point out the most important journals of his speciality. That is why the present paper relies mostly on *qualitative criteria* that can be adapted and applied to different fields of knowledge.

Table 2 enables funding agencies to easily qualify PIs and decide, for instance, about the maximum funding a given researcher should receive, to select referees, etc. It may also help editors of scientific journals to invite new reviewers and editorial board member; science academies to select new members; universities and laboratories to hire or to promote new faculty and researchers, etc. Finally, the table may also be useful for researchers to self-classify and compare their own achievements *vis-à-vis* those of their colleagues. The proposed mix of quantitative and qualitative indicators shown for each class in Table 2 is not exhaustive, but it is probably more complete than any other form of traditional judgment of a scientist's achievements and reputation, and can be applied across countries with varying scientific infrastructure.

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I am indebted to Robert Sherwood for his invaluable critical comments.

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