Brazilian Journal of Physics
ISSN: 0103-9733
luizno.bjp@gmail.com
Sociedade Brasileira de Física
Brasil

Matsas, George E. A.
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Brazilian Journal of Physics, vol. 42, núm. 5-6, diciembre, 2012, pp. 319-322
Sociedade Brasileira de Física
Sâo Paulo, Brasil

Braz J Phys (2012) 42:319–322
DOI 10.1007/s13538-012-0094-x

GENERAL AND APPLIED PHYSICS

What are Scientific Leaders? The Introduction of a Normalized Impact Factor

George E. A. Matsas

Received: 25 June 2012 / Published online: 2 August 2012

Abstract We define a *normalized impact factor* (NIF) suitable for assessing in a simple way both the strength of scientific communities and the research influence of individuals. We define those with NIF ≥ 1 as *scientific leaders* because they influence their peers at least as much as they are influenced by them. The NIF has two outstanding characteristics: (a) it has a clear and universal meaning and (b) it is robust against self-citation misuse. We show how a single lognormal function obtained from a simplified version of the NIF leads to a clear "radiography" of the corresponding scientific community. An illustrative application analyzes a community derived from the list of *outstanding referees* recognized by the *American Physical Society* in 2008.

Keywords Statistics · Philosophy of science · Social and economical studies

One of the most challenging aspects of defining comprehensive scientometric indexes is that it is not obvious how to take the field idiosyncrasies into account [1]. On the other hand, scientometric criteria are often useful for the proper agencies as they formulate their scientific policies. As part of the broad program of defining scientometric parameters, whose interpretation is as independent as possible of the research field, we define here the *normalized impact factor* (NIF) to assess *the strength of scientific communities* and *the influence of individual research*. The NIF has two outstanding characteristics: (a) it has a clear, universal meaning, which is applicable with equal efficiency to individuals belonging to quite distinct communities and (b) it is robust against self-citation misuse. As an illustration, we use the NIF to analyze a community derived from the list of *outstanding referees* recognized by the *American Physical Society* (APS) in 2008 [2]. We compare the NIF with the h-index and show that there is no clear correlation between them, indicating that the two indexes carry different pieces of information. Finally, we discuss the limitations of the NIF.

The NIF puts in context (i) *the influence exerted by the research of an individual* with respect to (ii) *the degree to which this individual has been influenced by his/her scientific community*. Our assumption is that while *citations* received by an individual reflect (i) [3, 4], the bibliographic *references* listed by him/her must reflect (ii). Hence, we define the NIF of an individual as

$$\text{NIF} \equiv \frac{\sum_i c_i/a_i}{\sum_i r_i/a_i}, \tag{1}$$

where c_i and r_i are the number of citations received and references included in his/her ith paper, signed by a_i authors. Thus, if the first paper of the publication list of some researcher is signed, for instance, by three authors (the researcher himself/herself and two other collaborators), has 30 references, and has received 20 citations, then $a_1 = 3$, $r_1 = 30$, $c_1 = 20$, and so on for

G. E. A. Matsas (✉)
Instituto de Física Teórica, Universidade Estadual Paulista,
R. Dr. Bento Teobaldo Ferraz 271, Bl. II,
01140-070, São Paulo, Brazil
e-mail: matsas@ift.unesp.br

the other papers. Including a_i avoids double counting of references and citations in multiauthored papers, which leads to the following important feature: in a *closed community* of *identical individuals* (i.e., who publish, reference and are cited by each other at the same rate), all members have NIF $= 1$. This is so because each reference corresponds to a citation. The NIF interpretation is therefore straightforward. We define as *leaders* those individuals with NIF ≥ 1 because they influence their peers at least as much as they are influenced by them. The existence of a universal reference value (NIF $= 1$) is one of the most satisfying aspects of this factor. Other features are highly field-dependent and, consequently, more difficult to interpret. Moreover, it is not easy to artificially boost one's NIF through self-citation because including extra references increases the denominator of (1). However, we note that the NIF is obviously silent about the intrinsic relevance of the research work itself. We might have leaders (in the sense that they possess NIF ≥ 1) influencing people to work on problems that ultimately do not pay off their research effort and vice versa. The NIF is clearly unable to evaluate the "quality of the leadership."

As an illustration, we analyze a community derived from the 2008 list of APS outstanding referees [2]. The methodology used is as follows: We have randomly selected 283 individuals (among the 531) and extracted their publication lists from the *ISI Web of Science* [5]. To avoid including homonyms, we entered the researcher name *and* affiliation exactly as they appear in Ref. [2] and recorded those with 20 or more papers. The derived community suffices for our purposes. Eventually, 223 individuals (authoring 22,611 papers) passed the criterion above, which led to 592,429 references and 597,390 citations. *Incidentally*, the total number of references is almost the same as the total number of citations, which is a necessary (although not sufficient) requirement for (approximately) closed communities. Obviously, our 223 individuals do not form a closed community. Because of resource limitations, we have actually carried our analysis using the *simplified normalized impact factor* (SNIF) defined as

$$\text{SNIF} \equiv \frac{\sum_i c_i}{\sum_i r_i}. \tag{2}$$

The typical difference between the SNIF and the NIF for ten randomly chosen individuals was less than 10 %. Even with this simplified procedure, we had to restrict our data collection to 3 months and the final update to 4 days [from June 21st to 24th (2008)]. In Fig. 1, the vertical bars show the *population probability density* generated from our data. The area below the graph gives the rate of individuals with SNIF in the corresponding interval. Interestingly enough, Fig. 1 is well fit by a lognormal distribution [6]:

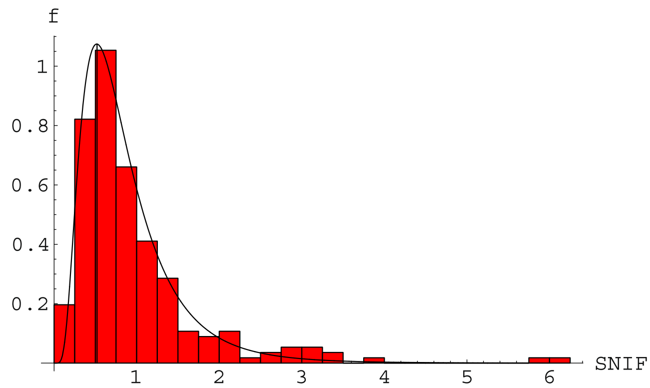

Fig. 1 The *vertical bars* show the population probability density obtained from our data. The area below the graph gives the rate of individuals with SNIF in the corresponding interval. The *solid line* is a lognormal distribution fit: $f(x) \equiv e^{-(\ln(x)-\mu)^2/(2\sigma^2)}/\sqrt{2\pi}\,\sigma x$ ($x \equiv$ SNIF) with $\mu = -0.3$ and $\sigma = 0.6$. Note that 68 % of the population has $0.4 < \text{SNIF} < 1.3$. Leaders represent only 31 % of the population

$$f(x) \equiv \frac{e^{-(\ln(x)-\mu)^2/(2\sigma^2)}}{\sqrt{2\pi}\,\sigma x},$$

where $x \equiv$ SNIF and, for the community under analysis, $\mu = -0.3$ and $\sigma = 0.6$. Indeed, μ and σ will depend on the community, but $f(x)$ is always unit-normalized:

$$\int_0^\infty f(x)dx = 1.$$

We can consider μ and σ as the "community fingerprint." *Because our sample consists of experts from high-energy experimentalists to condensed-matter theoreticians and our data are fit by a single lognormal distribution, we believe that the (S)NIF can be successfully applied to quite distinct populations, while keeping its simple and universal interpretation.* We see that 68 % of the population will be found between $\exp(\mu - \sigma) \approx 0.4$ and $\exp(\mu + \sigma) \approx 1.3$. We accordingly obtain from Fig. 1 that 68 % of our population has

$$0.4 < \text{SNIF} < 1.3.$$

The median that separates the population into two halves with respect to the SNIF value is given by

$$\widetilde{\text{SNIF}} \equiv \exp(\mu) = 0.74.$$

Thus, half of the population has SNIF ≥ 0.74. The SNIF expected value (or mean value) is given by

$$E(\text{SNIF}) \equiv \int_0^\infty dx x f(x) = e^{\mu+\sigma^2/2} = 0.89.$$

Note that $E(\text{SNIF}) > \widetilde{\text{SNIF}}$. *It can be numerically calculated from Fig. 1 that leaders represent only* 31 % *of the population.* (We note that the present author does not belong to the set of leaders.)

Up to this point, we used the (S)NIF to establish the relation of the scientific work of individuals with respect to their peers. Now, we proceed and propose a way to assess the *strength* and *homogeneity* of the scientific community itself. This is possible because of the good fit provided by the lognormal function for the SNIF distribution. The higher the median $\exp(\mu)$, the more "stretched" toward high NIFs will Fig. 1 be. This suggests the following definition for the *community strength*:

$$\text{CS} = \exp(\mu).$$

Similarly, the smaller the σ, the steeper the graph, in which case most people would have the same corresponding NIF and the community would be quite homogeneous. A prototype of a homogeneous community would be the one described in the beginning, namely, a closed community of identical individuals, in which all members have NIF = 1. This suggests the following relation as a measure of the *community homogeneity*:

$$\text{CH} = \frac{1}{\sigma}.$$

By the same token, the higher the σ, the flatter the distribution, which would characterize a nonhomogeneous community consisting of members with quite divers NIF values.

For the sake of comparison, we show in Fig. 2 the *h*-index [7] range (see also Ref. [8, 9]) assumed by individuals in a fixed SNIF interval. No obvious relationship is seen between "high" *h*-index and scientific leadership in the sense defined above: we find leaders with a relatively low *h*-index and nonleaders with a relatively high *h*-index. Notice that in general, one expects a correlation between the *h*-index and the number of papers. Let us consider for a moment the extreme case in which all N papers of some individual cite all his/her previous papers. In this case, the corresponding *h*-index would be $N/2$ and $(N-1)/2$ for N even and odd, respectively, solely due to self-citations. This can lead to quite high values. Albeit unrealistic, this illustration shows how the number of papers may influence the *h*-index. This is not the case with the NIF, which is basically insensitive to the paper number. The NIF is not expected to exhibit more than a moderate correlation with the *h*-index. As a result, the pieces of information provided by the NIF and *h*-index are fairly distinct.

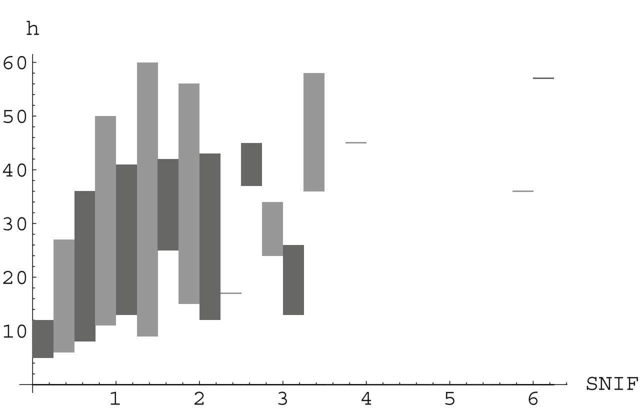

Fig. 2 The *bars* express the *h*-index range assumed by individuals with fixed SNIF. No obvious relationship between the SNIF and *h*-index is visible: we can find leaders with a relatively low *h*-index and individuals with SNIF < 1 with a relatively large *h*-index

In summary, assuming that our hypotheses (i) and (ii) above are meaningful, it seems fair to conclude that the NIF provides useful and novel information about the scientific work of individuals and of their corresponding communities. However, we would like to make some cautionary remarks concerning the use of this index. (The same remarks apply to the SNIF.) The first is that the NIF should be used to assess senior rather than junior scientists. How to define seniority is an open question on which some agreement has to be reached. Measured as a function of time, the NIF of junior researchers tends to exhibit a strong transient profile and to be mostly influenced by the supervisor's expertise, in which case the leader label would not apply. Moreover, the NIF does not distinguish between protagonist and coadjuvant authors cosigning the same papers. The reliability of the NIF as a way to assess leadership will depend on how much one's publication list does reflect the researcher's own expertise instead of that of his/her collaborators. In addition, researchers who solve a controversy may be less cited than those who have raised it. Depending on the circumstances, this may induce the NIF of the former to be lower than the NIF of the latter. To deal with these cases, other aspects (mostly subjective ones) should be taken into account [10]. Furthermore, the NIF is robust against the self-citation expedient, but not completely immune to it. Self-citations tend to increase and decrease the NIF for individuals with NIF < 1 and NIF > 1, respectively. If we assume the usual case, in which the *number of self-citations* (NSC) is small compared with the *total number of citations* (TNC) received by a researcher, $\text{NSC}/\text{TNC} \ll 1$, it is easy to derive from (1) that nonleaders will have an increased NIF value due to self-citation by a factor of $1 + \text{NSC}/\text{TNC} \approx 1$ having (some, but) not a dramatic net influence on the final NIF value. The NIF can be also influenced depending on the individual care and generosity when acknowledging the influence of others by including more or fewer references. However, we do not expect this factor to have a huge influence, either. Any unusual practice or artificial attempt to boost one's NIF by omitting crucial references should face prompt opposition from the peer-review system: whenever this is possible and necessary, referees help authors to improve their papers by calling attention to related references. On the other hand, widespread adoption of the NIF would probably induce authors to omit irrelevant references with the aim of receiving extra citations as a counterpart, which we regard as a "purifying" feature. Some concern can be also raised about to which degree the presence of reviews in the publication list could affect the NIF. Although reviews tend to include long reference lists, reflecting the contribution of various individuals to the corresponding topic, they also tend to be heavily cited because of their comprehensiveness. Eventually, the two tendencies should compensate each other and have no major effect on the NIF of senior scientists.

Despite the NIF robustness, it is obvious that no single parameter is able to clearly distinguish leaders from nonleaders. In spite of the possible difficulties that the NIF may face when applied to assess individuals, we emphasize that our *main* motivation to introduce this index was to provide a tool for producing more accurate "radiographies" of research communities as a whole (in which case, individual idiosyncrasies are "averaged" and should have no relevant net influence on the final diagnosis), leading thus to more efficient scientific policies. This is particularly important to communities in emerging countries, which are still fixing their standards and aim to eventually have a protagonist role in the global scenario.

Acknowledgements I am indebted to D. Gil de Oliveira and F. Montero for the help with data collection. I thank P. Ball, R. Meneghini, J. Montero, V. Pleitez, D. Vanzella, and E. Zanotto for the discussions. Partial financial support was provided by Conselho Nacional de Desenvolvimento Científico e Tecnológico and Fundação de Amparo à Pesquisa do Estado de São Paulo.

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