Scientometrics (2011) 89:607–629
DOI 10.1007/s11192-011-0464-0

An impact indicator for researchers

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Received: 22 March 2011 / Published online: 7 August 2011

Abstract The assessment of individual researchers using bibliometric indicators is more complex than that of a region, country or university. For large scientific bodies, averages over a large number of researchers and their outputs is generally believed to give indication of the quality of the research work. For an individual, the detailed peer evaluation of his research outputs is required and, even this, may fail in the short term to make a final, long term assessment of the relevance and originality of the work. Scientometrics assessment at individual level is not an easy task not only due to the smaller number of publications that are being evaluated, but other factors can influence significantly the bibliometric indicators applied. Citation practices vary widely among disciplines and sub disciplines and this may justify the lack of good bibliometric indicators at individual level. The main goal of this study was to develop an indicator that considers in its calculation some of the aspects that we must take into account on the assessment of scientific performance at individual level. The indicator developed, the h_{nf} index, considers the different cultures of citation of each field and the number of authors per publication. The results showed that the h_{nf} index can be used on the assessment of scientific performance of individual researchers and for following the performance of a researcher.

Keywords *h* index · Impact indicator · Normalization · Individuals

Introduction

The scientific activity of most researchers takes many dimensions and the assessment of his or her performance must depend on the policy of the institution to choose the components

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or dimensions that should be more highly valued at a certain moment. Academic performance is usually associated with the assessment peers make of the work of a certain individual and this is frequently related to raw indicators such as the number of documents, the type of journals where the documents were published or the number of citations attracted. If we want to assess the economic or social impact of researchers other indicators must be used like patents or the amount of funding attracted from private partners. The design of advanced indicators of academic performance has attracted a lot of attention in the last few years as national authorities, funding bodies or institutional leaders show a growing interest in indicators that can, automatically, rate the performance of academic staff. The application of bibliometric indicators to measure scientific performance of a country or university is generally accepted to give a fair assessment of the volume of research and its impact. However, when we are assessing the scientific performance at micro-level (small research groups or a single researcher) bibliometric indicators have to be applied carefully. At this level there are difficulties with the collection of the raw data and methodological problems in the subsequence analysis. Multidisciplinary databases, as ISI Web of Knowledge and Scopus, suffer from input errors that become relatively more important when we search a researcher or a small research group (Vieira and Gomes 2009). Furthermore, searches by author's name are confronted with the lack of a good quality author identifier. At present, identifiers used in ISI Web of Knowledge and Scopus must be used with at most care as it is very common that the same identifier encompasses two and frequently more researchers and the same author appears associated with several identifiers. The only alternative for reliable data collection on individual researchers is still the use of a personal Curriculum Vita that should be then complemented by the access to one of the well established databases. Methodological limitations are also present. The first methodological difficulty comes from the fact that we are using bibliometric techniques based on counting publications, citations and, possibly, a few other features of the publications. It should be clear that this cannot measure the scientific performance of a researcher in all its dimensions. Then we must consider that most bibliometric indicators have been developed and tested for large sets of data and their application to an individual or to a small research group calls for special care. For small sets, outliers may have a unexpected large effect and subtle differences of publication culture among disciplines and sub-disciplines may turn the interpretation of results into a very difficult or impossible job. The use of raw indicators as the number of publications and the number of citations are not sufficient to describe the scientific performance of a given researcher. There are just a few bibliometric indicators developed at individual level. Hirsch proposed a new indicator, called the *h* index, as a particularly simple and useful way to characterize the scientific output of a researcher. The scientific community has shown great interest in this indicator as it has the advantage of combining a measure of quantity (number of publications) and impact (number of citations) in a single indicator. Several indicators based on the concept of the *h* index have been proposed by other authors aiming to overcome the most important drawbacks of the *h* index. Egghe (2006) proposed the *g* index, Batista et al. (2006) the h_I, Jin et al. (2007) the *A* index, the *R* and *AR* index; Egghe (2008) the h_F index, Alonso et al. (2010) the *hg* index and Prathap (2010) index the h_m index these indicators being variations of the *h* index. The *g* index is intended as an improvement of the *h* index to measure the global citation performance of a set of articles in the g-core (Egghe 2006). It is defined as the largest rank (where papers are arranged in decreasing order of the number of citations received) such that the first *g* papers have (together) at least g^2 citations. The h_I is calculated as the ratio of the square of *h* index to the total number of authors of the documents in the h-core. If all publications in the h-core had a single author, then h_I equals *h*.

According to the proposers, this has the advantage of being less sensitive to different research fields (Batista et al. 2006). The h_F index is based on the concept of the h index, but uses fractional document counts and leaves the citations counts unchanged. In the calculation of this index each document is divided by the number of authors of the document (Egghe 2008). The A index was developed to correct the fact that the original h index does not take into account the exact number of citations of articles retained in the h-core. This index is simply defined as the average number of citations received by the publications in the h-core. Recognizing some limitations of the A index two new indices were proposed, the R index and the AR index. The R index is the square root of the sum of the citations of articles included in the h-core. The AR, besides taking into account the number of citations, makes use of the age of the publications in the h-core (Jin et al. 2007). The h_m index is a composite indicator $(C^2/P)^{1/3}$, where C is the number of citations obtained by the documents that belong to a given researcher and P is the number of publications. This indicator was proposed in order to generate a corrected quality measure that can be calculated using traditional bibliometric indicators (Prathap 2010). The hg index is based on the h and g index ($hg = (h * g)^{1/2}$) aiming to retain the advantages of the h and g index and to minimize the limitations of these two indices. The authors stated that the hg index allows a balanced view of the scientific production of a researcher (Alonso et al. 2010). Other indicators aiming to assess individual researchers have been proposed. Rons and Amez (2009) developed the impact vitality indicator in order to identify excellent researchers. This indicator measures how the scientific production of a researcher evolves over time giving lower weight to older publications. This evolution is analysed using the citing publications. The authors argue that this indicator is relatively easy to calculate, hard to manipulate and independent on the size and citation culture of each scientific field. The authors stated that the proposed indicator as a limited sensitivity to outliers in citation counts. Claro and Costa (2010) proposed an x-index to achieve a fair ranking of researchers in areas of engineering that are known to have very different publication and citation cultures. The scientific production of a researcher is compared with the scientific production of the researchers with most publications in the journal where the research under evaluation has published. The authors consider that using a set of journals where the researcher published instead of an established scientific field classification allows a better definition of the researcher's scientific profile. The authors recognize that the new indicator does not cover all dimensions of research work, but allows a comparison of the most active researchers across engineering areas.

This paper introduces a new indicator of the performance of a single researcher, the h_{nf} index, which is based on the h index concept and tries to achieve the following goals while preserving some of the desirable features of the h index.

- Limits the influence of a small set of publications with a large number of citations or of a set of publications with zero citations. Consider the case of a prestige institution that has been working on the development of an innovative methodology and a researcher A from another institution that gave a small contribution. The publication with this innovative methodology may have a high impact (measured by the number of citations) at the initial period and will continue to obtain a high number of citations in the subsequent years. This highly cited document may dominate the total number of citations and the mean citation rate per document for the researcher A. In calculating the h_{nf} in a way similar to that of the usual h index, this paper will count just as the second most cited paper of author A. On the other extreme, what van Raan (2004) calls sleeping beauties (papers that do not get citations in the immediate future, but only several years after publication) will weight down average indicators but do not affect h type indices like this one.

- The new h_{nf} index, like the usual h index, gives a simultaneous measure of quantity and impact of the bibliographic production and it makes still very clear to the researcher which of his/her papers are being considered as more relevant for the indicator.
- To be fair to individual researchers, the performance index should compensate for the citation cultures of different scientific fields and sub-fields and this is a recognized failure of the h index. The new h_{nf} index compensates this by the normalization of the citation count.
- The pressure to publish and to improve the h index has led to the growth of multi-authored papers even in cases of minor (or, it may be suspected, non-existent) contributions. This is corrected by using fractional counting in the h_{nf} index.
- A desirable feature of a performance indicator is its ability to predict the future behaviour of a researcher. This property will be discussed for several current indicators.

The h_{nf} index was applied to a fictitious example and to a real case aiming to present and to discuss the main features of the index. This paper is organized in four sections: Introduction, Methodology, Results and Discussion and Conclusions.

Methodology

Consider a researcher that, in a certain period, has authored P documents, each with a number of authors a_1, a_2,…a_j…a_p. Assume that a particular document, j, of type x, was published in year y in a journal belonging to subject categories $i = 1, 2, \ldots N$ (for document type and journal subject categories, we use the classification of Thomson Reuters Web of Science, WoS). Consider that, in a given period, this document obtained $C_{j(xyi)}$ citations; this number of citations is now normalized to obtain the corrected number of citations $C^n_{j(xyi)}$.

$$C^n_{j(xyi)} = C_{j(xyi)} \times \frac{I_{xy}}{\frac{1}{N} \times \left(\sum_{k=1}^{N} I_{xyk}\right)}$$

where I_{xyk} is the average number of citations of the documents of type x, published in year y in all journals of subject category k and I_{xy} is the average number of citations of all documents of type x published in year y,

$$I_{xy} = \frac{\sum_k M_{xyk} \times I_{xyk}}{M_{xy}}$$

where M_{xy} is the number of documents of type x published in year y in all journals of subject category k.

In this paper the normalization described above considered only the documents with at least one address from one of the UE_15 countries. This was adopted to limit the universe of papers used and will not affect the validity of the arguments and conclusions. As the final goal is to apply the new indicator to European researchers, this particular normalization procedure is expected to perform at its best.

In this process of normalization the time required for the maturation of citations in each subject category is not considered, although the use of variable citations windows might give a somewhat more accurate comparison. However, this would make the calculation of the indicator more complex and difficult to understand.

The next step is to fraction each document according to the number of authors. A document j with a_j authors will count as $1/a_j$. The total production of the author computed by fractional counting is:

$$\sum_{j=1}^{P} \frac{1}{a_j}$$

To compute the new h_{nf} index, the researcher's P documents are ranked in decreasing order of the number of normalized citations obtained in a given period as in Table 1.

Here $C_1^n > C_2^n > C_3^n \ldots > C_p^n$. An author has an $h_{nf} = \sum_{q=1}^{p} \frac{1}{a(q)}$ if the first p documents, $1 \ldots p$, have a number of citations such that $C_p^n \geq \sum_{q=1}^{p} \frac{1}{a(q)}$ and the reminder P–p documents have a number of citations such that $C_p^n \leq h_{nf}$. In other words, the value of the h_{nf} index is the maximum aggregate fractional count $\sum_{q=1}^{p} \frac{1}{a(q)}$ such that this sum is smaller or equal than the normalized number of citations of the pth document.

In the next section, this new index, is calculated and discussed for a fictitious example and also for a set of high performance Dutch researchers.

Results and discussion

Fractional counts

The treatment of multi-authored documents is a subject extensively discussed in bibliometrics. The increasing specialization and the technical sophistication of the research activities today require that researchers look for collaborations. Collaboration among research groups allows for a cross-fertilization of ideas and a complementarity of knowledge bases and technical capabilities that may be expected to lead to deeper work into a wider space of applications. Said in a different way, each collaborating group will

Table 1 Example for calculation of the h_{nf} index

Document rank	Number of authors	Documents count	Normalized number of citations	
1	a_1	$\frac{1}{a_1}$	C_1^n	$C_1^n > \frac{1}{a_1}$
2	a_2	$\frac{1}{a_1} + \frac{1}{a_2}$	C_2^n	$C_2^n > \frac{1}{a_1} + \frac{1}{a_2}$
3	a_3	$\frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3}$	C_3^n	$C_3^n > \frac{1}{a_1} + \frac{1}{a_2} + \frac{1}{a_3}$
…	…	…	…	…
p	a_p	$\sum_{q=1}^{p} \frac{1}{a(q)}$	C_p^n	$C_p^n \geq \sum_{q=1}^{p} \frac{1}{a(q)} = h_{nf}$
$p+1$	a_{p+1}	$\sum_{q=1}^{p+1} \frac{1}{a_{(q)}}$	C_{p+1}^n	$C_{p+1}^n < \sum_{q=1}^{p+1} \frac{1}{a_{(q)}}$
…	…	…	…	…
p	a_p	$\sum_{q=1}^{p} \frac{1}{a_{(q)}}$	C_p^n	$C_p^n < \sum_{q=1}^{p} \frac{1}{a(q)}$

enrich his lines of research by incorporating the depth of analysis provided by the other group's thinking or technical expertise. This being the case, we may expect the output (number of publications) of the collaboration to be at least equal to the sum of those of the collaborating groups before collaboration, but always going deeper and hopefully with a higher impact. Furthermore collaborating groups may be able to tackle problems that each group would not consider in isolation, thus getting further gains from the collaboration. This shows that, even if we follow a fractioning technique, collaborations will give a relevant pay off to the groups involved. In a publication with several authors, it is not yet common for authors to state their real contribution to the work. In some fields the position of the authors in the author's list can give some information about the relative relevance. In other fields the author's names are listed in alphabetical order and do not say anything about the contribution of each author. Some of the methods that involve accrediting publications to authors are: the normal counting where each author of the publication gets one publication, first author counting where only the first author gets a full credit (Cole and Cole 1973), the fractional counting (Burrell and Rousseau 1995) where each author gets 1/*N* publications, *N* being the total number of authors in the publication and the proportional counting (van Hooydonk 1997) where a fraction of the publication is attributed to each author taking into account her/his position in the author's list. Another question that may be raised is whether the number of citations of each document should be fractioned by the number of authors. Several studies have been made in order to determine the motivations for citing a given document (Brooks 1985, 1986; Frost 1989; Ahmed et al. 2004). These studies were based on content analysis and interviews of scientists. The studies based on content analysis showed that citations received by a document were directly related to the results contained in the document, theories or concepts, methodologies, historical background and to describe other relevant work (Frost 1989; Ahmed et al. 2004). The studies based on interviews of scientists aimed at explaining why some citations do not appear to cite work really presented in the cited publication. These studies showed that some authors cite a document because they are professionally connected and want these connections to be maintained, to show respect for an author that cited earlier work of the author's citing paper, the cited work was written by a respected author(s) or the cited document was published in an important journal (Brooks 1985, 1986). Concluding, we can say that there are two types of motivations for citing a document, professional motivations related with the real use of the content of the cited document and motivations related with the need to build social networks. Another important aspect of citation analysis is that of self-citations. In bibliometric evaluations self-citations are considered by many as a tool to inflate citation rates affecting the validity of research impact assessed through citation analysis. Author self-citations have been studied by several authors. Some of these studies showed that the reasons for an author to cite its own work are similar to those for other citations being a natural part of scientific communication. Bonzi and Snyder (1991) found that the main reasons for self-citations are: (1) to identify related work; (2) to show that the citing work builds on earlier work; (3) to suggest that the cited work is relevant in the subject; (4) to present this as the unique source of data; (5) to establish the author's authority in the subject and (6) to present the most accessible source. Studies at macro-level aiming to identify how the mean number of citations per publication and self-citations are related with the number of authors per publication have been done. Aksnes (2003) for a set of more than 45,000 documents observed that for a 3-year citation window self-citations represents about one third of the total number of citations, although, the percentage decreases if a higher observation window is used. He also found that for multi-authored documents self-citations present a minor part of the overall increase of citation rates. Vieira and Gomes (2010) showed that the mean citation rate per article increases with the number of authors for Biology & Biochemistry, Mathematics, Chemistry and Physics (scientific field used in the Essential Science Indicators). This increase is of 45, 52, 25 and 24% respectively as we go from the mean to twice the mean. Glanzel and Thijs (2004) also showed that the mean number of citations per document increases with the number of authors for a set of data extracted from the WoS. Considering all the aspects pointed out above we consider that citations should be fractioned by the number of authors if we are counting the total number of citations collected by a researcher along is active life as the citations of his/her papers are also due to other researchers he/she worked with. However, if we use the number of citations of each document, its impact, as a proxy of the document quality we consider that citations should not be fractioned. The quality of the document is not reduced by having another author in the list!

As the indicator is based on the concept of the h index we analysed the effect of using fractional counting on the calculation of this index for a fictitious example.

Fictitious example

Consider a researcher A that published 30 documents ($N = 30$) in a given period and that he/she was the unique author. The researcher decides to work with researcher B (with similar scientific profile) in order to complement knowledge or then technical capabilities. Several scenarios can be observed if we analyse the number of documents published and citations obtained considering a period with the same number of years as the period, before, where the researcher A published alone.

Scenario 1: The number of documents published is the double ($2N$) of that published by researcher A before collaboration and the number of citations (C) of each document is the same as before;
Scenario 2: The number of documents published and the number of citations of each document is the double ($2N$, $2C$) of that obtained by researcher A before collaboration;
Scenario 3: The number of documents published is the same (N), but the number of citations of each document is the double ($2C$) of that obtained by researcher A before collaboration;
Scenario 4: The number of documents published and the number of citations of each document remain the same of that obtained for researcher A before collaboration (N, C).

These are not the only scenarios possible. Other scenarios could also be considered: the number of documents and citations of each document could be lower than those observed for researcher A before collaboration. However, we considered that this scenario is too pessimistic as it would probably lead to the collaboration to be stopped. On the other hand, the studies that have been made where the effect of collaboration on the number of publications and citations is analysed showed that collaborations have a positive effect on the number of documents and citations (Glanzel and Thijs 2004).

These possibilities are better understood by the consideration of a simple example as presented in Appendix 1, where the number of citations for each case is proposed. Table 2 analyses how the value of the h index of this imaginary researcher A changes in the four scenarios described above.

The data in Table 2 suggest that the standard h index should be preferred if the number of documents, N, and the number of citations of each document, C, are not changed by the collaboration, but this is a very unlike situation as researcher A would not see a justification for collaborating. If the number of citations is doubled by the collaboration

Table 2 Values obtained for the h index of researcher A without and with collaboration

Without collaboration		With collaboration			
		Scenario 1	Scenario 2	Scenario 3	Scenario 4
Number of documents	N	$2N$	$2N$	N	N
Number of citations	C	C	$2C$	$2C$	C
h index					
Standard h index	11	17	22	22	11
Fractional counting of documents		11	13	13	6.5
Fractional counting of documents and citations		8.5	11	11	5.5

(scenarios 2 and 3), fractional counting of documents and citations would be recommended, but this is likely to be a very optimistic outcome of the collaboration. More likely, is scenario 1 where the number of documents duplicates without changing the number of citations of each document and this suggests that only fractional counting of documents should be used. If the number of citations increases somewhat, then the value of the h index will increase (up to two units when the number of citations doubles). This may be said to give a fair reward to the collaborating scientist and may be associated with some improvement of the "quality" of the joint papers.

These findings are in agreement with those of Schreiber (2009). Considering the results obtained for the fictitious example above, the h_{nf} index was calculated using fractional counting of documents and normal counting of citations. A similar strategy for document counts was recommended by Burrell and Rousseau (1995). The suggestion of van Hooydonk (1997) that the weight of each author should depend on his/her position on the list of authors is not considered as the order of authors varies from one field to the other.

Application of the h_{nf} index to a real case

To test this novel h_{nf} index in the real world, we consider a set of the most Dutch productive researchers in *Pharmacology & Pharmacy* and in *Mathematics Applied* according to the ISI Web of Knowledge in 2000–2007. We considered researchers associated with a university or research institution from the Netherlands and having at least 50% of his/her scientific production in a given period published in journals that belong to the subject category under study. The number of researchers used in each subject category represents altogether 15% of the total documents that contain at least one author's address mentioning the country Netherlands and published in journals that are classified in *Pharmacology & Pharmacy* and in *Mathematics Applied*, respectively.

In Tables 3 and 4, the values obtained for the h_{nf} index for the set of selected Dutch researchers from *Pharmacology & Pharmacy* and from *Mathematics Applied* are presented. The h_{nf} was calculated for documents published between 2000 and 2007 and the citations counted for the same period.

We can see that the h_{nf} index ranking, *in Pharmacology & Pharmacy*, differs significantly from the traditional h index ranking. Only researchers A and D have the same position in both rankings. These differences may result from the fractional counting penalizing researchers with more than average co-authors in their publications and from the normalization giving higher values to citations of documents in subject categories with lower than average citation mean.

Table 3 Values obtained for the h_{nf} and h index for the most Dutch productive researchers in *Pharmacology & Pharmacy*

Author	h index	Rank (h index)	h_{nf} index	Rank (h_{nf})
A	29	1	10.726	1
D	22	2	8.084	2
H	18	3	5.598	11
E	17	4	6.464	6
J	16	5	5.680	10
L	16	5	6.163	9
G	15	6	6.559	5
M	15	6	5.525	12
C	13	7	7.344	3
I	12	8	7.082	4
Q	12	8	4.613	14
K	11	9	6.237	7
O	11	9	4.651	13
B	10	10	6.166	8
N	10	10	4.246	17
P	9	11	4.326	16
F	8	12	4.526	15

Table 4 Values obtained for the h_{nf} and h index for the most Dutch productive researchers in *Mathematics Applied*

Author	h index	Rank (h index)	h_{nf} index	Rank (h_{nf})
G	7	1	4.843	7
D	6	2	5.033	5
I	6	2	4.417	9
A	5	3	6.833	1
C	5	3	5.833	2
F	5	3	5.333	4
H	5	3	5.583	3
J	5	3	3.667	11
K	5	3	3.000	13
E	4	4	4.667	8
M	4	4	3.000	13
Q	4	4	3.083	12
B	3	5	5.000	6
L	3	5	4.083	10
N	3	5	2.833	14
O	3	5	2.833	14
P	3	5	2.167	15

The values of the h_{nf} index are normally lower than those obtained for the h index due to two cumulative effects. On the one hand, the number of authors per document in this subject category is frequently large and fractioning has a sizable effect. On the other hand, this is a subject category with higher mean number of citations per document than *Mathematics Applied*. The documents published in *Pharmacology & Pharmacy* obtain normally a large number of citations, but when the normalization is used there is a depreciation of the actual citation count because the mean number of citations per document in this subject category is high relative to the general average of all subject categories. Of course the relevance of the index is not due to its absolute values but to the relative values of different researchers. Researchers E, F, H, J, L, M, N, O, P and Q, with a better position in the h index ranking, are researchers that published in other categories where documents get usually more citations.

In *Mathematics Applied*, the differences between the rankings are still more pronounced. The results in *Mathematics Applied* suggest that the h_{nf} index allows a better differentiation among the researchers considered in this subject category than the h index. The values of the h_{nf} index are of the same order of magnitude and sometimes higher than those of the h index. The number of authors per document does also influence this result. In this subject category fractional counting has a little effect as many papers have just two or three authors. On the other hand, *Mathematics Applied* is a subject category with a lower average number of citations per document and for this set of authors the actual citations are then appreciated by the normalization process. For *Pharmacology & Pharmacy* the contrary occurs. The typical document has a larger citation count and this number is depreciated by the normalization process.

We now consider the possibility of using the h_{nf} index to compare the performance in *Pharmacology & Pharmacy* and in *Mathematics Applied*. Table 5 lists the features of the two sets of Dutch researchers considered here, ranked by their h_{nf} index calculated for the documents published between 2000 and 2007. The percentage of documents in the h and h_{nf} core is also presented.

It is not surprising that researchers from *Pharmacology & Pharmacy* still come in the top when ranked by the h_{nf} index. In fact the corrections we considered may be assumed to compensate for the differences on the citation cultures, but not for the differences in the rate of publications in the two subject categories. Part of this difference comes from the intense collaboration in *Pharmacology & Pharmacy* (with an average of 6.0 researchers per document compared with 2.4 researchers per document for *Mathematics Applied*) and the fractional counting for researchers corrects for this. However, the fractional counting of documents is very different for the researchers in the two subject categories (with an average of 23.3 for *Pharmacology & Pharmacy* compared with an average of 10.2 in *Mathematics Applied*). The larger productivity in *Pharmacology & Pharmacy* induces larger values of the h_{nf} index. It should be noted, however, that the h_{nf} values differ a lot less than the h values for the two set of researchers.

If we look now at the percentage of documents in the h and h_{nf} core we see that the number of documents considered in the h_{nf} core is much higher than that in the h core. Using an index that represents a higher number of documents of a given author allows a better description of his/her scientific production.

For a full comparability of researchers in *Mathematics Applied* and in *Pharmacology & Pharmacy* a further correction should be introduced. A simple way to do this is to ensure that the average value of the newly corrected h_{nf} index is the same for the two set of researchers (as the difference between their standard deviations is relatively small). This corrected h'_{nf} index is easily obtained using the average values shown in Table 6 for each subject category (Fig. 1).

Table 5 Values obtained for the h_{nf} and the h index for the set of researchers from *Pharmacology & Pharmacy* and *Mathematics Applied*

Authors	Subject category	Total number of documents	Mean number of authors per document	Mean number of citations per document	Documents count $\left(\sum_{a=1}^{p} \frac{1}{a(p)}\right)$	h index	Documents in the h core (%)	h_{nf} index	Documents in the h_{nf} core (%)
A	PP	294	7.422	11.86	50.731	29	10	10.726	23
D	PP	134	3.940	10.27	23.513	22	16	8.084	37
C	PP	111	5.574	5.65	25.717	13	12	7.344	27
I	PP	122	5.187	5.23	27.174	12	10	7.082	30
A	MA	14	1.643	4.79	10.500	5	36	6.833	57
G	PP	147	5.551	4.54	28.519	15	10	6.559	21
E	PP	85	6.642	11.15	16.007	17	20	6.464	44
K	PP	75	6.349	5.28	16.183	11	15	6.237	37
B	PP	100	6.556	3.95	34.259	10	10	6.166	20
L	PP	146	4.111	4.52	25.394	16	11	6.163	24
C	MA	29	2.586	2.52	12.750	5	17	5.833	41
J	PP	104	6.306	6.50	17.208	16	15	5.680	33
H	PP	94	4.766	10.74	15.538	18	19	5.598	38
H	MA	30	2.400	2.87	15.333	5	17	5.583	47
M	PP	82	6.702	8.00	13.060	15	18	5.525	43
F	MA	28	2.500	2.39	12.083	5	18	5.333	39
D	MA	18	2.167	10.17	9.700	6	33	5.033	56
B	MA	15	1.667	2.73	11.533	3	20	5.000	40
G	MA	22	3.045	5.36	8.843	7	32	4.843	50
E	MA	32	1.969	1.53	18.833	4	13	4.667	25
O	PP	124	7.183	3.45	21.469	11	9	4.651	22
Q	PP	108	7.144	5.06	18.114	12	11	4.613	27
F	PP	81	7.037	3.37	23.770	8	10	4.526	22

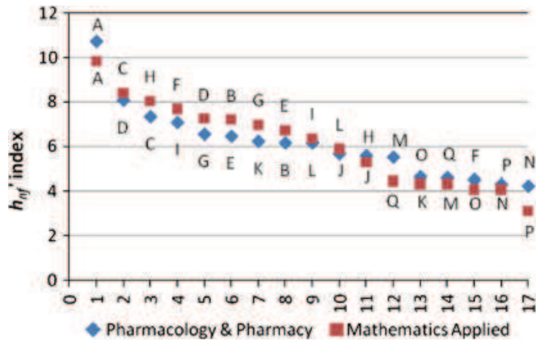
Table 5 continued

Authors	Subject category	Total number of documents	Mean number of authors per document	Mean number of citations per document	Documents count $\left(\sum_{a=1}^{p} \frac{1}{a(p)}\right)$	h index	Documents in the h core (%)	h_{nf} index	Documents in the h_{nf} core (%)
I	MA	22	3.272	7.32	7.792	6	27	4.417	55
P	PP	108	5.306	10.89	22.092	9	8	4.326	19
N	PP	91	5.681	3.73	17.519	10	11	4.246	23
L	MA	18	2.222	1.78	9.167	3	17	4.083	44
J	MA	19	3.105	5.21	6.417	5	26	3.667	53
Q	MA	30	3.000	1.63	10.833	4	13	3.083	30
M	MA	16	2.563	2.38	6.667	4	25	3.000	44
K	MA	16	2.500	3.06	7.167	5	31	3.000	44
N	MA	15	1.933	1.73	8.667	3	20	2.833	33
O	MA	17	3.000	2.12	6.810	3	18	2.833	35
P	MA	14	1.643	0.79	10.167	3	21	2.167	29

Table 6 Features of the indices related with the selected authors

Index	Number of documents (P)			Documents count $\left(\sum_{a=1}^{p} \frac{1}{a_{(p)}}\right)$			Authors per document (A/D)			h index			h_{nf} index		
Subject category	$\langle P \rangle$	σP	%RSD	$\left\langle \left(\sum_{a=1}^{p} \frac{1}{a_{(p)}} \right) \right\rangle$	$\sigma \left(\sum_{a=1}^{p} \frac{1}{a_{(p)}} \right)$	%RSD	$\langle$A/D$\rangle$	σ A/D	%RSD	$\langle h \rangle$	σh	%RSD	$\langle h_{nf} \rangle$	$\sigma_{h_{nf}}$	%RSD
Mathematics Applied	20.9	6.4	31	10.2	3.3	32	2.4	0.54	22	4.5	1.2	28	4.248	1.301	31
Pharmacology & Pharmacy	118.0	50.4	43	23.3	9.0	39	6.0	1.10	18	14.4	5.3	37	6.117	1.627	27

Fig. 1 Corrected h_{nf} values showing how researchers of different areas can be compared. The researchers in each area are ranked by the value of the h'_{nf} index



It is fair to say that this corrected index, h'_{nf}, allows for a comparison among these researchers independently of the very different cultures of the two disciplines. Ranking the 34 researchers according to the h'_{nf} index, we get what appears to be a disordered series of researchers of the two disciplines. Further studies aiming to correct for differences in publication rate among subject categories are called for, but we leave this till later and the results will be presented considering only the h_{nf}.

In Table 6 are presented some indices calculated for the two set of researchers aiming to identify some of the features of the researchers of these two subject categories.

It is clear that the h index for researchers from *Pharmacology & Pharmacy* is not only larger on average than that of *Mathematics Applied*, but also the standard deviation and the relative standard deviation are larger. This suggests that researchers in the *Pharmacology & Pharmacology* set are more heterogeneous what may be confirmed by the number of publications and, more important by the share of their publications in very different subject categories. Making the normalization of citations and fractional counting for documents, we achieve h_{nf} values that make researchers from *Pharmacology & Pharmacy* look more homogeneous. In fact the relative standard deviation for the h_{nf} index is lower than that obtained for the h index in this subject category.

Ability of the h_{nf} index to describe the performance of a researcher

In order to discuss the ability of the h_{nf} index to describe the increase/decrease of the performance of a researcher along the time, we plot in Fig. 2 the values of the h index and h_{nf} index, always for a 8 years observation window. These indicators were calculated for 10 Dutch researchers from *Pharmacology & Pharmacy*.

Before discussing the results, it must be said that only tentative conclusions may be drawn as we are following these researchers for a very short period of only 5 years in relation with the 8 years observation window used. The general conclusion is that the h_{nf} index can follow the increase/decrease of performance in a way similar to the h index. Both can evidence an increase/decrease of up to 20% in this short period. If we go into detail, the differences between h and h_{nf} indices may be as higher as 10%. It seems fair to conclude that the h_{nf} index may be a good alternative to the h index to follow the performance of a researcher with the advantage that it is more difficult to manipulate both by going into subject categories with higher number of citations rates or by incorporating researchers with small contributions.

Figure 3 shows the total number of documents, the total number of citations, the h index and the h_{nf} index calculated for 1996–2003 and 2000–2007 aiming to determine the

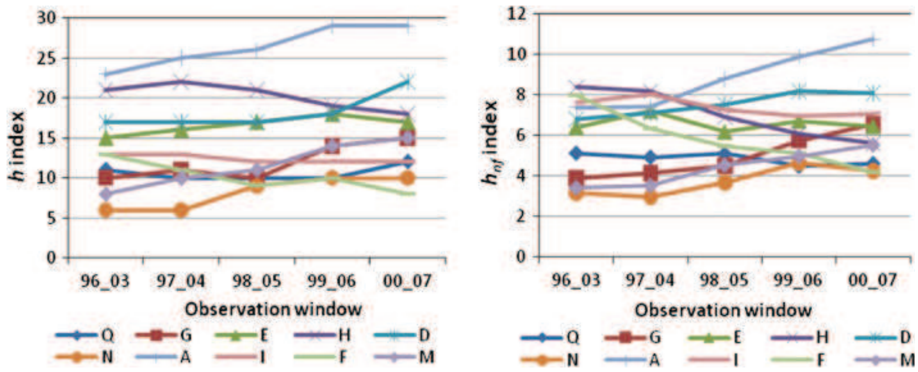


Fig. 2 Values of the h and h_{nf} index for five periods, between 1996 and 2007

predictability of each indicator. As above, we consider a sample of top performing Dutch researchers from *Pharmacology & Pharmacy*. Authors F and H considered above were not introduced in this analysis as it is considered that the researchers are entering in retirement. The number of documents and citations for authors F and H decreased up to 55 and 59% respectively between the period 1996–2003 and 2000–2007.

The results suggest that the h index and the total number of citations have the highest predictive power. This may be explained if we consider that a given researcher normally gains prestige along his/her career. Initially the work developed by a given researcher may be unknown at the scientific community and take some time to get recognition over time. This may justify why the researchers selected for this study have higher values for the total number of citations and the h index in the period between 2000 and 2007 than between 1996 and 2003. We have to be careful in this analysis as the criterion used for selection of this set of researchers may lead to relatively young ascending researchers and to other that have fully developed their potential or are even entering in retirement.

By and average and for a short time span of 4 years the predictability of h and h_{nf} index are similar but a few exemplary cases may deserve a comment. Researcher I gets the largest value for the h_{nf} index in 1996–2003. This same researcher has an h index in 1996–2003 below the average and this is due to the fact that most of the journals where he publishes are listed only under the subject category *Pharmacology & Pharmacy* while the other researchers have most of the documents published in journals also listed in other subject categories with higher average citation rates. Under normalization, these other researchers see their index pressed down leaving researcher I in the top positions.

The h_{nf} index and the other indicators based on the h index concept

We now discuss the main differences obtained when these researchers are ranked using the h_{nf} index and using other indicators based on the concept of the h index. The *A, R, AR*, g, h_F, hg, h_m, h_I were calculated for these researchers and the results compared with that obtained when the h_{nf} index is applied. The results presented in Table 7 were calculated considering the documents published between 2000 and 2007 and the citations counted for the same period.

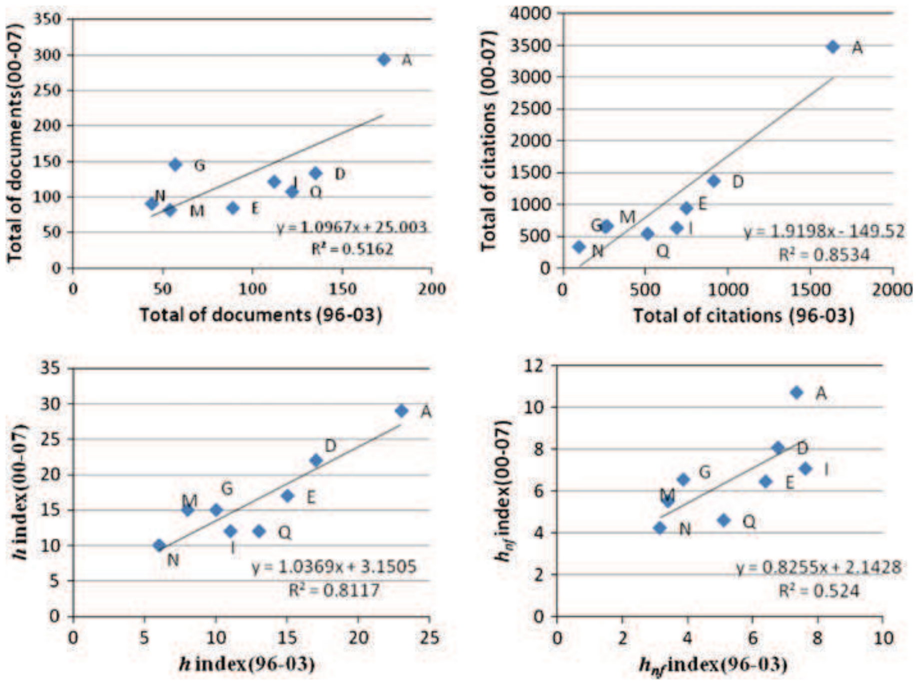


Fig. 3 Values obtained for the total number of documents, total number of citations, the *h* and h_{nf} indices in the period 1996–2003 and 2000–2007 by researchers from *Pharmacology & Pharmacy*

The results show that when the h_{nf} index and the h_I index are used some researchers of *Mathematics Applied* appear in the top of the rankings. For the remaining rankings researchers from *Pharmacology & Pharmacy* are always ranked first than researchers from *Mathematics Applied*. For the h_{nf} ranking these results were already discussed above. The h_I index considers in its calculation the total number of authors of the documents that define the *h* core. Researchers with low *h* index but with a large number of authors rank in the last positions in the h_I ranking. Researcher A and B from *Mathematics Applied* have in average one author per documents for the documents in the *h* core and this explain the top position in the rankings.

If the h_{nf} ranking is compared with the h_I ranking we can observe for some researchers significant variations of their positions. Researcher B and D from *Mathematics Applied* have a better position in the h_I ranking than in the h_{nf} ranking. These are researchers that publish documents with a few authors (1 author and 2 authors in average respectively) than researchers from *Pharmacology & Pharmacy*, but the documents from these researchers receive in average a few citations than those of researchers from *Pharmacology & Pharmacy* with better positions in the h_{nf} ranking when compared with those documents that belong to the same subject categories. This shows the need for a field normalized indicator in relation to citations. Another reason may explain a large different in the positions between the two rankings for a given researcher. If a researcher has a document in the *h* core with a large number of authors this would decreases significantly the h_I index (Batista et al. 2006). However, for this set of researchers this special case was not found.

Table 7 Different positions of researchers in the rankings when different indicators based on the concept of the *h* index are used

Authors	Subject category	Position in the rankings								
		h_{nf}	*A*	*R*	*AR*	*g*	*hg*	h_m	*hi*	h_F
A	PP	1	1	1	1	1	1	1	2	1
D	PP	2	3	2	2	2	2	2	6	2
C	PP	3	9	9	11	9	9	7	3	4
I	PP	4	15	11	12	11	11	8	16	5
A	MA	5	22	22	21	22	22	22	1	18
G	PP	6	5	5	5	6	8	9	7	6
E	PP	7	4	4	3	4	4	4	5	3
K	PP	8	19	15	16	16	14	12	15	8
B	PP	9	13	13	8	13	13	14	11	12
L	PP	10	11	8	9	8	7	10	13	9
C	MA	11	31	27	31	30	26	24	18	19
J	PP	12	10	7	7	7	5	6	12	10
H	PP	13	2	3	4	3	3	3	8	7
H	MA	14	24	23	24	23	23	23	22	23
M	PP	15	6	6	6	5	6	5	21	11
F	MA	16	27	24	25	24	24	25	10	22
D	MA	17	8	17	19	17	18	13	9	17
B	MA	18	26	31	30	31	31	27	4	26
G	MA	19	21	20	20	20	20	20	20	21
E	MA	20	29	26	26	26	27	31	14	27
O	PP	21	14	12	13	12	12	15	27	14
Q	PP	22	7	10	10	10	10	11	28	13
F	PP	23	18	18	17	18	17	18	19	15
I	MA	24	12	19	18	19	19	17	23	24
P	PP	25	17	16	15	15	16	19	26	20
N	PP	26	16	14	14	14	15	16	24	16
L	MA	27	33	33	33	33	33	32	32	28
J	MA	28	20	21	22	21	21	21	25	25
Q	MA	29	30	29	27	27	28	29	33	31
M	MA	30	25	30	29	29	29	28	34	30
K	MA	31	28	25	23	25	25	26	17	29
N	MA	32	32	32	32	32	32	33	30	32
O	MA	33	23	28	28			30	31	33
P	MA	34	34	34	34	34	34	34	29	34

Comparing now the h_{nf} ranking with the rankings provided by the use of the remaining indicators we can also observe significant differences between the positions of the researchers. These differences are explained for most of the cases by the normalization and fractionalization processes applied in the h_{nf} index that allow a better assessment of the scientific production of the researchers. For the researchers D and I from *Mathematics Applied* and Q from *Pharmacology & Pharmacy* significant differences are observed. These researchers have 2 documents (D and I) and 1 document (Q) highly cited in the h-core. These documents influence markedly the A index and give to these researchers a top position in the A ranking. We can also say that the R, AR, g and h_m index are also influenced by these documents, although, in a lesser extent. This is better evidenced by researcher Q where this highly cited paper represents about 35% of the total citations obtained by the documents in the h-core. The influence of the highly cited documents in the g index was previously discussed by Alonso et al. (2010) and in the h_m index by Prathap (2010). The h_m index is also influenced significantly by uncited documents (Prathap 2010) and this is unfair for those researchers that published a large number of new documents that do not get citations yet. The h_{nf} index is immune to these documents as discussed earlier.

The differences observed in the h_{nf} ranking and in the h_F ranking are explained by the normalization process in the h_{nf} index. As the h_{nf} index, also the h_F index divides each document by the number of authors, but leaves the citation scores unchanged. Researchers with a mean citation per document lower than the average of the documents that belong to the same subject categories will rank lower in the h_{nf} ranking but may rank in the top positions in the h_F ranking.

Conclusions

This study shows that the h_{nf} index can be used to measure the scientific performance of a researcher. The h_{nf} index keeps the same good features of the h index:

- It combines a measure of quantity (publications) and impact (citations).
- The h_{nf} is not affected by documents with an extremely high number of citations and documents with zero citations are ignored;
- The h_{nf} index can be used to predict the future behaviour of a given researcher as suggested by the study of a few cases while a larger number of cases may allow more accurate conclusions in future;
- It allows working with the small set of publications of a single author.

In top of these common advantages the h_{nf} index presents other important strong points:

- The citations obtained by each document are normalized in relation with the subject category of the journal where the document was published, this allowing the comparison of researchers working in different fields, although the time required for the maturation of citations is not yet considered;
- The calculation of the h_{nf} index considers the number of authors that sign each document, making it difficult to inflate results with coauthorship of documents for reasons other than good scientific performance;
- The number of documents in the h_{nf} core is larger than that considered in the h core allowing a better description of the scientific performance of a given researcher;
- The h_{nf} index is harder to manipulate.

The h_{nf} index combines several important aspects of the scientific performance of a given researcher. The results obtained in this study show that the h_{nf} index can be used to assess and to follow the scientific performance of researchers.

Appendix 1

Calculation of the *h* index for the scenarios presented in Table 2 (see Tables 8, 9, 10 and 11).

Table 8 Values of the *h* index without and with fractional counting for scenario 1 in the fictitious example presented in the "Results and discussion" section

Without collaboration		With collaboration				
		Scenario 1				
Rank of documents	Number of citations	Rank of documents	Number of citations	Documents per author	$\sum_{q=1}^{p} \frac{1}{a(q)}$	Citations per author
1	50	1	50	0.5	0.50	25.00
2	30	2	50	0.5	1.00	25.00
3	28	3	30	0.5	1.50	15.00
4	25	4	30	0.5	2.00	15.00
…	…	…	…	…	…	…
10	14	10	23	0.5	5.00	11.50
11	12	11	20	0.5	5.50	10.00
12	10	12	20	0.5	6.00	10.00
13	8	13	19	0.5	6.50	9.50
14	5	14	19	0.5	7.00	9.50
15	5	15	18	0.5	7.50	9.00
16	5	16	18	0.5	8.00	9.00
17	4	17	17	0.5	8.50	8.50
18	4	18	17	0.5	9.00	8.50
19	3	19	14	0.5	9.50	7.00
20	2	20	14	0.5	10.00	7.00
21	1	21	12	0.5	10.50	6.00
22	1	22	12	0.5	11.00	6.00
23	1	23	10	0.5	11.50	5.00
…	…	…	…	…	…	…
30	0	60	0	0.5	30.00	0
h index						
Standard *h* index	11	17				
Fractional counting of documents		11.00				
Fractional counting of documents and citations		8.50				

Table 9 Values of the *h* index without and with fractional counting for scenario 2 in the fictitious example presented in the "Results and discussion" section

Without collaboration		With collaboration				
		Scenario 2				
Rank documents	Number of citations	Rank documents	Number of citations	Documents per author	$\sum_{q=1}^{p} \frac{1}{a(q)}$	Citations per author
1	50	1	100	0.5	0.500	50
2	30	2	100	0.5	1	50
3	28	3	60	0.5	1.5	30
4	25	4	60	0.5	2	30
…	…	…	…	…	…	…
10	14	10	46	0.5	5	23
11	12	11	40	0.5	5.5	20
12	10	12	40	0.5	6	20
…	…	…	…	…	…	…
22	1	22	24	0.5	11	12
23	1	23	20	0.5	11.5	10
24	1	24	20	0.5	12	10
25	1	25	16	0.5	12.5	8
26	1	26	16	0.5	13	8
27	0	27	10	0.5	13.5	5
28	0	28	10	0.5	14	5
…	…	…	…	…	…	…
30	0	60	0	0.5	30	0
h index						
Standard *h* index	11	22				
Fractional counting of documents		13				
Fractional counting of documents and citations		11				

Table 10 Values of the *h* index without and with fractional counting for scenario 3 in the fictitious example presented in the "Results and discussion" section

Without collaboration		With collaboration				
		Scenario 3				
Rank documents	Number of citations	Rank documents	Number of citations	Documents per author	$\sum_{q=1}^{p} \frac{1}{a(q)}$	Citations per author
1	50	1	100	0.5	0.50	50.00
2	30	2	100	0.5	1.00	50.00
3	28	3	60	0.5	1.50	30.00
4	25	4	60	0.5	2.00	30.00
…	…	…	…	…	…	…

Table 10 continued

Without collaboration		With collaboration				
		Scenario 3				
Rank documents	Number of citations	Rank documents	Number of citations	Documents per author	$\sum_{q=1}^{p}\frac{1}{a(q)}$	Citations per author
10	14	10	46	0.5	5.00	23.00
11	12	11	40	0.5	5.50	20.00
12	10	12	40	0.5	6.00	20.00
…	…	…	…	…	…	…
21	1	21	24	0.5	10.50	12.00
22	1	22	24	0.5	11.00	12.00
23	1	23	20	0.5	11.50	10.00
24	1	24	20	0.5	12.00	10.00
25	1	25	16	0.5	12.50	8.00
26	1	26	16	0.5	13.00	8.00
27	0	27	10	0.5	13.50	5.00
28	0	28	10	0.5	14.00	5.00
…	…	…	…	…	…	…
30	0	60	0	0.5	15.00	5.00
h index						
Standard *h* index	11	23				
Fractional counting of documents		13.00				
Fractional counting of documents and citations		11.00				

Table 11 Values of the *h* index without and with fractional counting for scenario 4 in the fictitious example presented in the "Results and discussion" section

Without collaboration		With collaboration				
		Scenario 4				
Rank documents	Number of citations	Rank documents	Number of citations	Documents per author	$\sum_{q=1}^{p}\frac{1}{a(q)}$	Citations per author
1	50	1	50	0.50	0.50	25
2	30	2	30	0.50	1.00	15
3	28	3	28	0.50	1.50	14
4	25	4	25	0.50	2.00	13
…	…	…	…	…	…	…
10	14	10	14	0.50	5.00	7
11	12	11	12	0.50	5.50	6
12	10	12	10	0.50	6.00	5
13	8	13	8	0.50	6.50	4
14	5	14	5	0.50	7.00	3
15	5	15	5	0.50	7.50	3

Table 11 continued

Without collaboration		With collaboration				
		Scenario 4				
Rank documents	Number of citations	Rank documents	Number of citations	Documents per author	$\sum_{q=1}^{p} \frac{1}{a(q)}$	Citations per author
16	5	16	5	0.50	8.00	3
17	4	17	4	0.50	8.50	2
18	4	18	4	0.50	9.00	2
19	3	19	3	0.50	9.50	2
20	2	20	2	0.50	10.00	1
21	1	21	1	0.50	10.50	1
…	…	…	…	…	…	…
30	0	30	0	0.50	15.00	0
h index						
Standard *h* index	11	11				
Fractional counting of documents		6.50				
Fractional counting of documents and citations		5.50				

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