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Impact Factor and other metrics for evaluating science: essentials for public health practitioners

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Abstract

The quality of scientific evidence is doubly tied with the quality of all research activities that generates it (including the "value" of the scientists involved) and is usually, but not always, reflected in the reporting quality of the scientific publication(s). Public health practitioners, either at research, academic or management levels, should be aware of the current metrics used to assess the quality value of journals, single publications, research projects, research scientists or entire research groups. However, this task is complicated by a vast variety of different metrics and assessment methods. Here we briefly review the most widely used metrics, highlighting the pros and cons of each of them. The rigid application of quantitative metrics to judge the quality of a journal, of a single publication or of a researcher suffers from many negative issues and is prone to many reasonable criticisms. A reasonable way forward could probably be the use of qualitative assessment founded on the indications coming from few but robust quantitative metrics.

Key words: peer review, bibliometric indicators, impact factor, h-index, eigenvalue, webometric indicators, g-index

Introduction

In many cases, public health decisions are (or, at least, should be) based on the best scientific evidence available. Often, but not always, the best scientific evidence is found in publications presented in highly ranked journals. This also reflects the adoption of quality standards in reporting scientific information by some of those journals (see for example [1-3]). The quality of scientific evidence is doubly tied with the quality of all research activities that has generated it (including the "value" of the scientists involved) and usually, but, again, not always, is reflected by the reporting quality of the scientific publication(s). For example, decisions on priorities given to funding of different public health projects are also related to the quality of the projects' proponents. For this reason, public health practitioners, either at research, academic or management levels, should be aware of the current metrics used to assess the quality value of journals, single publications, research projects, research scientists or entire research groups.

Pushed by the generalized diminishing funds for research, science evaluation is becoming more and more important to guide decisions on resource allocation and to manage the scarce available resources transparently. The methods to evaluate the quality of science are either qualitative or quantitative [4,5].

The qualitative method includes the peer review process and the evaluation by expert panels. The peer review is notoriously applied during the submission process of a manuscript for publication in a journal, while the experts' evaluation is often applied for grading projects submitted in response to funding calls or for selecting candidates for tenure in academic or other research positions. Being subjective methods of evaluation, qualitative methods are prone to many biases. Some journals use more rigorous quality checks than others, but overall peer-review is not perfect [6]. For example, reviewers might be more prone to reject papers not in line with current paradigms or for not citing what they (and not the author) believe to be crucial publications. Flawed papers may get through while many excellent papers that only need some improvements are rejected by highly competitive journals based on priority considerations [6]. Or a review panel might value the personal connections held by candidates in a position (or proponents of projects for funding) over personal achievements (the "old boys network" effect, [7]). Both those biases, in the long run, cause a form of "academic prostitution" in which work is done to please editors or reviewers rather than to add further scientific knowledge [8].

The quantitative methods for research evaluation are developed within the discipline of *Scientometrics* which aims at measuring science, viewed as an information process with bibliometric and econometric tools [5, 9,10]. In this field, a widely used tool is the citation analysis, i.e. statistical studies on the research cited in the bibliographies of journal articles. Starting from *Bibliometrics*, the term *Informetrics* identifies a more general portion of information science dealing with mathematical and statistical analysis of communication processes in science and includes *Webometrics* and other sub-disciplines, referring to different applications of the scientometric methodology to analyze scientific information on the web [11].

Evaluating the quality of the information contained in published papers quantitatively should not sound like a totally new exercise to public health practitioners, as meta analysis, the single "instrument" providing the most solid evidence for public health decisions, often contains a routine evaluation of the quality of the data coming from the single studies included in the analysis [12]. However, the direct implementation of algorithms provided by bibliometricians for evaluating journals, papers or researchers, is far from simple. Fuelled by the rapid expansion of huge online databases, a plethora of new scientific performance indicators have been proposed during the past few decades (the so called "metric explosion") so that it is impossible to even count all today's bibliometric metrics [13].

In the following pages we aim to briefly highlight the quantitative metrics most used and current developments in science evaluation. Our aim to provide public health practitioners with a first guide and overview of the vast "panorama" of science evaluation measures, attempting to stress different aspects and facets of the phenomenon.

Metrics for evaluating science

Publication counts is a well known bibliometric technique and it is simply the count of scientific publications produced by a researcher or a research group. The total number of publications is an output indicator but it does not indicate the value of the publications or their quality. However, scientists citing documents make public statements of intellectual recognition of cited authors [14] and citations are an indicator of the dissemination of an article within the scientific community [15]. Citation analysis consists of statistical elaborations of the citations in the bibliographies of the articles, as the number of times a publication or an author has been cited in other scientific works. The co-citation analysis is a method used to detect when couples (or groups) of articles are cited together in other articles, giving even the idea of interaction between disciplines. Science areas, and the connection between articles and authors, can be mapped through the citation network detection [16].

Biases in citation analysis arise because of differential citation behaviour between disciplines or citer motivation. An analysis of over 50.000 *Science* papers highlighted the strong relationship between the number of citations a paper receives and the number of references included in the paper reference section [17]. According to Peter Lawrence (Emeritus Professor at University of Cambridge), the type and number of citations has become the measure how fashionable and well funded a field of research is rather than its true quality [18]. With the proliferation of scientific literature, the papers are read less critically or even not at all. Quantity and quality of citations seem not important any more given the practice to cite many publications to support or comment a work instead of citing the few most relevant ones [19]. Moreover, the increased abuse and misuse of self citations, negative citations and corrections to previous articles can distort impact measures (see below).

Impact Factor

Citation practices strongly influence the most widely diffused bibliometric indicator to evaluate scientific research, the Impact Factor (IF). The IF was ideated by Eugene Garfield, an information scientist, and Irving Sher, a biochemist, statistician, and linguist, in the 1963. Their aim was to provide a useful method of selecting core journals (i.e. the most cited) to be recorded in a database of cited and citing articles (citation matrix) in the different scientific disciplines, called "Science Citation Index" (SCI), created by the Institute for Scientific Information (ISI, today Web of Science by Thomson Reuters, a profit company)[20].

The correct name of this indicator is *Journal* Impact Factor as Garfield and Sher aimed at setting up "a simple means of comparing the quality of small journals with large ones". They studied "the chronological distribution of citations, especially in biochemistry and molecular biology and observed that about 25% of citations referred to articles published just a few years back. So, they concluded that the 2-year impact factor could be a remarkable predictor of future journal performance". Afterwards, the Journal Citation Reports (JCR) - a database of journals reporting IF values and other indices such as Immediacy Index and Cited Half Life – was developed, becoming a standard tool for library science and publishing activities purposes [21].

The IF formula of a Journal X in year 2010 is calculated as follows: ***IF(X, 2010)= B/C*** where:

- A= sum of total citations of items published in 2010 by Journal X present in any items of any journals in Thomson database (e.g. indexed journals)
- B= 2010 citations of Journal X items published in 2008-09 (this is a subset of A)
- C= number of primary research and review articles published in 2008-09 into Journal X

Derived from IF, are 2 other bibliometric indicators: the Immediacy Index and the Cited Half Life index. The immediacy index is calculated based on the papers published in a journal in a single calendar year.

For example, the 2010 Immediacy Index of Journal X would be calculated as follows:

Immediacy Index (X) 2010 = A/B where:

- A = the number of times items published in 2010 into Journal X were cited in indexed journals during 2010
- B = the number of articles, reviews, proceedings or notes published in 2010 by Journal X.

The Journal Cited half-life is the median age of articles that were cited in a given year. Cited half-life shows how quickly articles published in a given journal, taken as a set, cease to be cited.

The IF overcomes the shortcomings of absolute (or total) citation counts. It eliminates some of the biases of such counts which favor large journals over small ones, or frequently issued journals over less frequently issued ones, and of older journals over newer ones. Many biases of IF have been suggested in the past few years ([22-

Textbox 1. The most frequently reported criticisms of the IF [23-25].

- IF does not capture the multidimensional phenomena of a journal's influence on science;
- Confusion over the definition of citable items (the denominator in the calculation; see also [24]) and a lack of transparency by Thomson on this issue [23];
- IF inflated by citations to article types (such as editorials or letters), not accounted for in the denominator [24];
- Review journals often have higher impact factors and thus have an advantage over non-review journals;
- Cross field comparisons meaningless because of differences in absolute IF from one discipline to another;
- Subjective definition of disciplines included into JRC fields
- The two-year citation window is too short and penalizes some fields and their journals
- Multidisciplinary journals, which offer a mixed set of papers in terms of fields, produce a "mixed" IF of little use;
- No IF available ff the journal is not indexed by Thomson Reuters;
- Journal coverage is biased against certain nations and languages (like English)
- IF is biased by citation in negative or about retracted articles [23]
- IF is biased by the "Blockbuster paper" effect ([23]; see text)
- There is a skewed distribution of citations in most fields

25] and references therein) and are not repeated here. A concise list of IF reported biases is shown in textbox 1. However, it is worth mentioning that comparisons of JIF between disciplines should take into account the fact that journal diffusion among readers (e.g. potential citers) greatly differs among subject categories or journal types (generic journals will physiologically have more readers than specialist ones). An effort to normalize impact factors for different fields has been carried out [26,27]. What emerged was the "Median Impact Factor" (MIF), i.e. the median value of all journal impact factors in the subject category [27], and it is also included in the JCR.

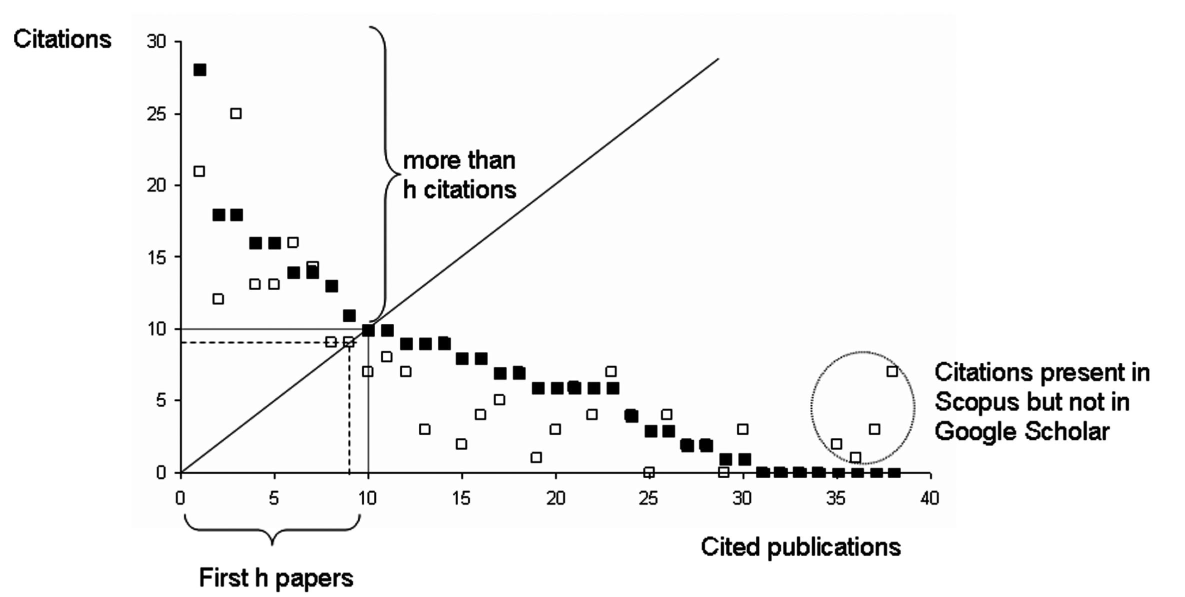
Although designed for evaluating the impact of journals within a discipline, the IF is used to evaluate the impact of single articles, scientists, research groups and even entire departments. However, even if a scientist has his/her own article published in a high IF journal, this does not necessarily mean that it will have an equally high impact on the scientific community. Consider the case of an author that publishes an article in a highly impacted journal but his article totalizes zero citations in the successive years. This article has zero impact on science (apart from exceptions derived from articles cited long time after being published [28]) . However, the article's author profits from the citation (and IF) tracking effect of "blockbuster" papers [23] , the ones having the "real" impact on the scientific community. Often, in highly ranked journals, a quarter of all IF citations can be attributed to those few "star articles" published each year [29].

The h-Index

As already mentioned, the Impact Factor is not representative of the impact of the individual journal articles or of the individual researcher impact. In 2005, Jorge Hirsch proposed the h-index, a number that combines publication activity and citation influence, attempting to measure the productivity and impact of the work published by a scientist. It is defined as follows: "A scientist has index h if h of [his/her] N_p papers have at least h citations each, and the other (N_p – h) papers have at most h citations each" . For example, a researcher with 9 publications that each have 9 or more citations has an h-index of 9 [30]. The h-index can be calculated for free by several tools like the scHolar Index Index (http://interaction.lille.inria.fr/~roussel/projects/scholarindex/index.cgi); QuadSearch (http://quadsearch.csd.auth.gr/index.php?s=2&lan=1); Publish or Perish (http://www.harzing.com/pop.htm), that also provides g-index, citations per paper and other indices, obtaining citations from Google Scholar, or with fee subscription by the Web of Knowledge or Scopus.

Notably, the h-index of a researcher will differ based on the database used as indicated in Figure 1 for one of the authors of this paper at the time

Figure 1. Example calculations of the h-index and effect of the database used as source of citations for one of the authors of this paper at the time of writing.



Open and closed quadrates are citation counts using Scopus and Google Scholar respectively. Scopus retrieved 38 cited documents, Google Scholar 46. The h-index (Scopus) = 9; the h-index (Google Scholar) = 10.

of writing. As shown in figure 1, the use of Google Scholar as a citation source database will give a higher h-index than Scopus. In fact the h-index in Scopus = 9 while the h-index in Google Scholar = 10. Moreover, 8 publications were present in Google Scholar but not present in Scopus and 4 were present in Scopus but not in Google Scholar.

Reported biases and disadvantages of Google Scholar are its inclusion of non-scholarly citations, double counting of citations, less frequent updating, uneven coverage across disciplines and less comprehensive coverage of older publications/citations [31]. Researchers that are also working in highly visible organizations or research groups will have a higher probability of being noticed and their work cited over researchers that produce similar quality papers but are less in the science spotlight. Another bias reflects the already mentioned citing misbehaviour when an author prefers to cite a given researcher or article because his or her work represents the current "gold standard" in that authors' discipline ignoring the less dogmatic work of others so as not to displease the reviewers.

Other biases refer to the number of authors per paper (the h-index tends to favor disciplines with larger groups); the different citation practices in different fields (the numbers of citations per paper are different among disciplines); the dependency on the stage of a researcher's career as h-index penalizes young scientists, i.e. the short careers, being bounded by the total number of publications.

The h-index has also been recently proposed for journals [31]. Analogous to its use for authors, the h-index for journals may provide a robust measure of sustained and durable performance of journals, rather than articles.

The g-index

The g index was introduced by Leo Egghe in 2006 . The g-index is a modification of the h-index that takes into account the presence of highly cited papers beyond the h value. It is defined as follows: "The g-index is introduced to measure the global citation performance of a set of articles. If this set is ranked in decreasing order of the number of citations that they received, the g-index is the (unique) largest number such that the top g articles received (together) at least g^2 citations. It is shown that the g-index inherits all the good properties of the h-index and, additionally, takes better into account the citation scores of the top articles. This yields a better distinction between, and order of, the scientists from the point of view of visibility" [32].

Both the h-index and the g-index should complement each other to represent a global value of a scientist.

Eigenfactor

The Eigenfactor score measures the total influence of a journal using network based ranking systems. It was ideated by the University of Washington, on the view that the scholarly literature forms a vast network of academic papers connected to one another by citations in bibliographies and footnotes [33]. It is published in the JCR together with the other impact indices reported above. Notably, eigenfactor analysis aims at answering the question "what should I read to pursue my research?" by finding items that are relevant (a matching problem) and of sufficient high quality (a ranking problem) [34]. The algorithm implemented by eigenfactor is similar to Google's PageRank algorithm. Journals are rated according to the number of incoming citations, with citations from highly-ranked journals weighted to make a larger contribution to the eigenfactor than those from poorly-ranked journals [35]. As a measure of importance, the Eigenfactor score scales with the size of a journal. All else equal, larger journals have larger Eigenfactor scores. As such, Eigenfactor scores are not directly comparable to impact factor scores, which are a measure of per-article prestige. Eigenfactor is calculated based on the citations received over a five year period, excluding journal self-citations(see http://www.eigenfactor.org/). Interestingly, the Eigenfactor has resulted to be well correlated with total number of cites [36].

Webometric indicators

With the rapid diffusion of the information on the web, methods for measuring the online impact and influence of scientific information have been quickly developed giving birth to the Webometrics (or Cybermetrics) a term first coined in 1997 by T. Almind and P. Ingwersen [37].

Google Scholar is an alternative source of data to the Web of Knowledge or Elsevier's Scopus to search citations by a page rank system based on the Autonomous Citation Index (ACI) [33]. An ACI system can automatically create a citation index from literature in electronic format by autonomously locating articles, extracting citations, identifying citations to the same article that occur in different formats, and identifying the context of citations in the body of articles. The viability of ACI depends on the ability to perform these functions accurately.

The Web Impact Factor, elaborated by P. Ingwersen in 1998, is calculated on the number of web pages in a web site receiving links from other web sites, divided by the number of web pages published in the sites that are accessible in the web. It should be used within a single country and in a specified language and topic [33, 38].

Finally, it is worth mentioning the Usage factor (UF). For those web resources, as for example an on-line journal, that follow an agreed international set of standards and protocols governing the recording and exchange of online usage data [39], it is possible to define the UF as follows:

Usage Factor Journal X = total usage (usage items of Journal X data for a specified period) /

total number of articles published online during a specified period

All webometrics are also tightly linked to the Open Access (OA) model of publication that gives the possibility of being read, and eventually cited, worldwide and without subscription. Furthermore, the copyright of the article remains with the author. The OA journals are peer reviewed and many of them already have an impact. For example, among the most important OA editors are BioMed Central, Pubmed Central (in which the research results of NIH publicly funded research are published), PLoS (Public Library of Science), DOAJ (Directory of Open Access Journals) and others.

The OA model tackles the problem of the growing scarcity of resources and increasing costs of research, including journals subscriptions. It is useful to help young researchers, and not only, to publish more freely and without being necessarily part of a closed circuit of scientists, or potential citers. For example, counting the online accesses and download of a research paper is a short-term indicator that can help to predict the citations of the article in the future years [33].

How to evaluate scientific output: a few hints for the public health practitioner

Public health practitioners at all levels are constantly called upon to take decisions based on the best available scientific evidence. Sometimes different available options are ranked following the quality of the researcher producing it or considering the impact of the journal in which the information was published. Since authors of scientific papers use citations to indicate which publications influenced their work, scientific impact can be measured as a function of the citations that a publication receives [40]. Therefore, when public health administrators and policy makers need quantitative measures of scientific impact, citation analysis is a natural choice. However, many metric measures, including the well known Journal Impact Factor, were not designed to assess the value of individual scientists and make little sense when applied for this purpose. Although Impact Factor could be adjusted to fit single researcher evaluation (adjusting by data source, specialty, half-life of article citations, number of journals and researchers in the field, coauthors, time periods) [41] , other measurement metrics are possibly better suited for this task, such as the h-index. Following the parallels proposed by M. A. Hernan, Journal Impact Factor has biases that are evident to trained epidemiologists (Table 1), even when applied for its original purpose (e.g. comparing journals) [42]. Several adjustments also seem to be needed in the case of h-index (see Table 1).

The rigid application of quantitative metrics to judge the quality of a journal, of a single publication or of a researcher suffers from many negative issues and is prone to many reasonable criticisms. A set of editorials, recently published in Epidemiology ([42] and references therein) and in Nature ([7, 13] and related commentaries) have highlighted the pros and cons of ranking research. All the indicators are potentially influenced by the citation behaviour of the researchers that can be distorted due to the fact that they are under pressure from the "Publish or perish" dogma. As noticed by others [6], this process can lead to writing articles with " the least publishable unit" (salami science[43]), clearly wrong papers, petty trivia, and ultra thin salami slices where even their authors (except for incurable megalomaniacs) would confidentially acknowledge triviality" ("junk" in the words of J. P. Ioannidis and colleagues [6]). Virtually anything can be published, as the current system does not penalize junk publication but it rewards productivity [6]. On the other hand, the adoption of qualitative systems alone (e.g. peer review or review panels) could lead to distorted choices because of the "old boys network" bias when well established scientists act as gatekeepers blocking the "entrance" of new researchers who are not already part of their network or who do not share the same scientific views (see for example [44]).

A reasonable way forward would probably be the use of a qualitative assessment by a panel review founded on assessment through few robust quantitative metrics. In any case, any method will be imperfect if intellectual honesty and scientific ethics are not put to the forefront. We conclude with a sentence by BG Charlton: "Yet real science must be an arena where truth is the rule; or else the activity simply stops being science and becomes something else: Zombie science" [45].

Table 1. Epidemiological parallels of two popular metrics to assess journals and single researcher quality, Journal Impact Factor (modified from [24]) and Author h-Index.

	Hypothetical cancer follow up study	*Journal Impact Factor*	*Author h-Index*
Subjects	Individuals	Published items	Citations of paper belonging to Author X
Source population	Selected cohort	Journals present into ISI database	Papers published by Author X
Eligibility criteria	Defined in the study protocol	Publications in the 2 years before year Y	All papers published by Author X during his/her career
Outcome	Number of cases of diseases	IF of journal X in year Y	H index of author X
Classification bias	Outcome misclassification	Citations in Journal X of items published in the same Journal X	Self citations
Subjects contributing to denominator	Individuals at risk of developing the disease	Articles designed as primary, review or "front matter" by Thomson Scientific	not applicable
Subjects not contributing to denominator	Individuals with disease	Commentaries, letters, editorials not considered substantive papers by Thomson Scientific	not applicable
Criteria to determine which subjects contribute to the denominator	Defined by the study protocol	Unspecified	not applicable
Other possible adjustment factors	Age, gender, race, etc.	Subject area	Data source, specialty, time period

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