Indexes for Evaluating Research Groups: Challenges and Opportunities

Areli Andreia dos Santos(✉) and Moisés Lima Dutra

PGCIN, Federal University of Santa Catarina, Florianópolis, Brazil
{areli.santos,moises.dutra}@ufsc.br

Abstract. Several indexes have been proposed to evaluate the scientific research productivity. These indexes are useful for several management decisions, such as career development and distribution of financial capital to scientific researches. In the last two decades, several works have proposed indexes to measure how productive and relevant the work of a researcher is. Some of these indexes aim to be applicable to evaluate an individual researcher and/or groups of researchers, applying the same formula for both situations. However, in some cases, this application is not straightforward. In this work, we studied the main indexes used to evaluate productivity of scientific researchers, discuss their aspects and organize them according to their characteristics, by pointing up the variables that are used to compose each index. We also analyzed works that applied the h-index for a group of researchers, highlighting the different ways adopted for this application. Furthermore, we discussed the opportunities to expand these metrics in a fairer way to evaluate quantitative and qualitative aspects for groups of researchers. After a literature review of these indexes, we conclude that the h-index can be used in many ways to evaluate groups of scientific researchers. Hence, there are other challenges and opportunities in the proposal of indexes to evaluate these groups, such as performing experiments for smaller groups, evaluating social aspects and defining better ways for selecting articles to evaluate the research productivity of groups.

Keywords: Scientific research evaluation · Indexes · Metrics · Group of researchers

1 Introduction

In the last decades, the access to scientific publications such as articles and journals was facilitated by the use of the Internet. In addition, several indexes [1–3] were proposed to compare and evaluate how relevant a publication is and what are its impacts on society. These indexes are useful specifically to evaluate quantitative aspects, measuring how much a researcher, a group of researchers and even a university or country produces in science. One of the main uses of these statistical data is for a fairer distribution of funds and other resources among scientific entities [4].

E. Bisset Álvarez (Ed.): DIONE 2021, LNICST 378, pp. 41–53, 2021.
https://doi.org/10.1007/978-3-030-77417-2_3

Expressing such an intangible value as scientific productivity is not an easy task, and there will always be distortions of the reality. The most primary idea is to use the number of papers, but it only measures quantity, not quality. Another common metric is the number of the citations, that can express how much relevant a scientific paper is to other scientists. The number of citations is the most relevant and traditional metric to evaluate the impact and relevance of a scientific article.

In order to combine both quantity and quality, several indexes (i.e. h-index, e-index, i10index, etc.) had been proposed by using both the number of papers and citations, aiming to measure not only the quantity, but how useful a paper is. After that, self-citation became an issue, and other indexes [2, 3, 5, 6] were proposed to avoid this distortion. More recently, aspects considering the online environment have also been applied to these indexes, bringing new metrics such as clicks and downloads, i.e. the altmetrics. But the number of papers and citations still remain as one of the most relevant metrics for measuring production and relevance in science.

While some of the proposed indexes are used to calculate data for an individual researcher [1, 7, 3], others are used in the calculation for a group of researchers [8–10]. In this work, we consider a group of researchers as any group of two or more researchers, which could be students, professors, and other academics who work together. This group setting can vary from a small group composed of a few research colleagues who are applying for a small and non-financed project to a large research group working on an international project with many researchers and resources from different countries. Besides, a group of researchers can also be considered on a larger scale, such as a group of all the researchers of a country or even all the researchers in a given field considering a global scale.

Some of the proposed works claim that the application of existing metrics originally created for evaluating individual researchers to a group of researchers is a straightforward task, e.g. there are several approaches that use the h-index to evaluate research groups [11, 12]. However, these approaches use specific h-index extensions to analyze groups. The main extensions of h-index for groups are: i) the h_1-index [11], which considers an entire institution or department, taking into account all the papers of this institution/department in its calculation; ii) [13, 14] calculate an average of the h-indexes for a group of researchers; iii) a so-called successive h-index [15] calculates the h-index of an institution by identifying as top researchers all those who have a number of publications greater than or equal to a predetermined limit value for the h-index. According to this proposal, to calculate the h-index for an entire country, it is necessary to identify the top institutions that have an h-index greater than or equal to this predetermined limit value.

Nonetheless, even the established ways to extend the h-index for evaluating groups raise questions: All the papers of an author who worked in several institutions should be considered, or only the ones published by him/her while working in his/her present institution? Shall we consider all the citations of all authors, regardless of their co-authors? Or should we focus only on the papers in which all members of the group participate? Could we also focus on the papers in which only a few members of the group participate? The number of authors in each paper must be considered? All these questions are still not answered and can be grouped in one big question: which articles should be selected to measure how relevant the scientific research productivity of a group is?

There are in the literature some surveys that address the indexes used to measure scientific researchers [4, 16, 17]. While some of them focus on analyzing a specific knowledge area [16, 17], some others are more generalists [4]. These works are focused on metrics to analyze papers and researchers, but there is no specific emphasis for a group of researchers. Still, some other works proposed the application of the h-index for a group of researchers [11, 13–15]. These works mostly used a transformation, such as averaging, to apply the h-index to analyze a specific field, by comparing different institutions. However, to the best of our knowledge, none of these works summarized the two approaches: indexes to evaluate both individuals and groups of researchers. Considering the problem of applying metrics that consider both quantitative and qualitative aspects for a group of researchers, the objective of this work is to study the main indexes used to measure science, by means of evidencing which values are used to compute each index. Subsequently, based on a literature review, we present the main challenges and opportunities for research in this area.

The remainder of this article is organized as follows. In Sect. 2, we summarize the research methodology that was used to search and select the main works related to scientific measurement. In Sect. 3, we summarize the main aspects of each index in a table, and present a more detailed explanation for each one. In Sect. 4, we discuss the challenges and opportunities for measuring the scientific production of research groups. Finally, in Sect. 5 we present the conclusions of this work.

2 Research Methodology

In this section we present a state-of-the-art on indexes used to evaluate productivity in science. We conducted an exploratory search, and found the main papers through Google Scholar. An initial search in SCOPUS database was performed, but since no relevant results were found, we focused on the first source.

The terms used in this exploratory search were: "Measurement scientific research", "Index scientific research", "Bibliometric scientific research", "Index Group of researchers", and "h-index for groups". Several false positive results were shown in Google Scholar, however an initial group of ten papers was selected. From them, new works were included. After reading each paper, we could identify some surveys, and most of these papers were focused on highlight pros and cons for each metric. However, none of them presented a summary combining the two indexes for individual and groups of researchers. Subsequently, we evaluated each description for the indexes in order to identify and simplify the way in which these indexes are presented. Thus, we summarized the description of each index in Table 1, which presents the main outcome of this work, and depicts the application of each index for groups of researchers. Finally, we analyzed the existing works in order to identify the challenges to assess the productivity of a group of researchers. The focus of our analysis is to propose research opportunities for this area.

In the next section, we present a literature review summarizing the main indexes and providing a more detailed explanation of each index.

Table 1. Metrics to evaluate research productivity

Metric	Used for	Source	Short description
Number of papers	Groups and Individuals	Number of papers	Counter of the number of papers
Number of citations	Groups and Individuals	Number of citations	Counter of the number of citations
h-index (Hirsch 2005)	Individuals	N. of papers and citations	Total of *h* papers with at least *h* citations each
h(2)-index (Kosmulski 2006)	Individuals	N. of papers with n^2 citations	Total of *h* papers with at least h^2 citations each
g-Index (Egghe 2006)	Individuals	N. of top papers	Total of g papers with at least g^2 citations altogether
A-index (Jin et al. 2007)	Individuals	Average citations	Average of citations of an author's publications
R-index (Jin et al. 2007)	Individuals	N. of citations	$\sqrt{}$A-index (square root of A-index)
AR-index (Jin et al. 2007)	Individuals	N. of papers and citations, age of papers	$\sqrt{}$A-index normalized by the age of the article
RP-Index (Altmann et al. 2009)	Individuals	N. of papers and citations, weight of author contribution and age of the article	NC_{ij} considers all variables described. Similar to h-index, but considers the NC_{ij} not h
e-index (Zhang CT. 2009)	Individuals	N. of citations	Prunes the total number of citations by a number of h^2
Index h_m (Schreiber 2009)	Individuals	N. of citations, papers and authors	Counting the papers fractionally according to the inverse of the number of authors
i10-index (Google 2011)	Individuals	N. of papers and citations	Number of papers with at least 10 citations each
m-Quotient (Hirsch 2011)	Individuals	h-index and age of 1^{st} paper	Divide the h-index by the number of years since the first publications
Crown Indicator	Groups and Individuals	N. Citations	Compares a paper with the average citations of other similar articles

(*continued*)

Table 1. (*continued*)

Metric	Used for	Source	Short description
AIF - Author Impact Factor (Pan and Fortunato 2014)	Individuals	Average of citations, time window	Average number of citations from an author's papers in the last years
PageRank-Index (Senanayake 2015)	Individuals	PageRank of Google Search applied to an article	The higher the PageRank of a papers is, the higher is its relevance
h_{α}-index (Hirsch 2019)	Individuals	h-index	The number of papers where an author is the main author
h_1-index (Mitra 2006)	Groups	N. of papers and citations	Total of *h* papers with at least *h* citations each
h_2-index (Mitra 2006)	Groups	N. of researcher and h-index of researchers	Total of *n* researchers with an h-index of at least *n* each
Successive h-indices (Shubert 2007)	Groups	h-index	Successive application of h-index formula using other values
CP-Index (Altmann et al. 2009)	Groups	RP-Index	Number of researchers *n* with an Total of *n* researchers with an RP-index of *n* least each
h_2/h_1–ratio (Rousseau et al. 2010)	Groups	h_1-index, h_2-index	h_2-index /h_1-index

3 Literature Review

Table 1 presents the source for the calculation of each one of the indexes that are used to measure quantity and/or quality for individuals and groups of individuals. After, we present a more detailed review of each index that is currently being used to assess scientific outputs.

3.1 Summary Table of Indexes for Evaluating Researchers

In order to provide a simpler way to identify each index, we organized them chronologically, accordingly to the time of each proposal, as shown in Table 1. Metrics to evaluate research productivity. The first column of Table 1 provides the index names. The second one depicts whether the index is used for groups or individuals. The third column presents the data source used to calculate each index. Finally, the fourth column provides a short description of how to calculate the index.

A more detailed explanation of Table 1 is presented in the next section.

3.2 Main Indexes to Evaluate Scientific Research

The first presented metrics, the counters, brings the simplest idea to evaluate productivity. More specifically, the number of papers to evaluate quantity and the number of citations to evaluate quality, i.e. how relevant a research is to others. It is the most seminal idea of an index and most of the subsequent works are based on these counters. Then, we explain the h-index itself, as well as other indexes to evaluate research productivity for individuals and groups of individuals.

Number of Papers. It is the simpler way to evaluate scientific productivity, by straightforwardly counting all papers by a researcher or a group of researchers. The number of papers can also be specified, for instance, to consider only articles from a given area or only papers published in high impact factor (IF) journals. However, this metric cannot be used to evaluate quality, and so, it is usually classified as a quantitative measure [4].

Number of Citations. It is a most sophisticated counter, that considers the number of times where a certain paper is cited, and thus used by another scientific work [16]. This metric can be used to evaluate researchers, a group of researchers and even journals, by the sum of citations for a certain group of papers. However, this metric cannot be used to evaluate a solid contribution in a certain field, because it could be biased if a single paper is highly cited. Another bias of the number of citations is that authors that are focused on surveys can have a higher number of citations than a scientist who is effectively producing new contributions.

h-index. One of the most famous metrics that combines number of papers and number of citations [1]. If one paper has at least one citation, the h-index is 1. If two papers have at least two citations each, the h-index is two. Consequently, if ten papers have at least ten citations each, the h-index is ten, and so on. This became one of the most used indexes in the last decade, being used in Web of Science Indexing, Scopus Indexing, Google Scholar Indexing, among others.

h(2) index. "A scientist's h(2) index is defined as the highest natural number such that his h(2) most-cited papers received each at least $[h(2)]^2$ citations." (Kosmulski 2006) [5]. For instance, a h(2) of 10 express the value of 10 papers that were cited at least 100 times each. Accordingly to Kosmulski, this index is useful to the chemistry area, and can be adapted to a h(n)-index, accordingly to another specific field, even using the h-index as an h(1)-index. This index was one of the first ones to try overcome the self-citation issue.

g-index. This metric uses an input of papers ranked by citations. The higher the number of citations, the higher in the list will be the article. As a result, the g-index delivers the largest number of g-articles that had g^2 citations altogether. This index gives a higher value than the h-index and can be biased by a few articles with a high number of citations [2].

A-index. Proposed by Jin et al. in 2007 [18]. It is named A-Index because it is calculated with the average of citations of an author's publication and takes into consideration the same papers used to evaluate the h-index. This index might not be ideal to compare researchers with different number of papers, since the average can be biased by a high number of papers with only a few citations, even when the individual has solid contributions with other works.

R-index. Proposed by Jin et al. in 2007 [18], it was presented as a solution to the A-index problem. In order to normalize the number of papers, the R-index is simply calculated by the square-root of the A-index.

AR-index. Also proposed by Jin et al. 2007 [18], this index is claimed as a solution for one of the h-index problems: when a top-researcher retires or even reduce the number of his/her publications, his/her h-index can still have a high value. Thus, this index is a variation of R-index, but instead of use the square root for calculating the average of citations, the number of citations is normalized by the age of a paper. The older the paper, the less this paper will impact the index.

RP-Index. Proposed by Altmann et al. in 2009 [19]. RP stands for Research Productivity. This index considers the NC_{ij}, that is calculated by the number of citations, divided by the age of the paper and multiplied by a factor of collaboration of an author for the paper, which is a number varying from 0 to 1. The NC_{ij} factor is then used similarly to the h-index as "the largest natural number *x* such the top *x* publications have at least in average a value of *x* for their NC_{ij}" [19].

Index h_m. Schreiber in 2009 [20] proposed an index that considers co-authorships. Through this index, the papers are counted fractionally according to the inverse of the number of an author's rank.

e-index. Proposed in 2009 by Zhang CT [3]. This index was created as a criterion for when more researchers have the same h-index value, but a different number of citations. Must be used only for highly cited authors, it prunes the number of citations by a number of h2 citations to calculate a modified h-index.

i10-index. Proposed by Google in 2011 and used in the Google Scholar platform. This metric corresponds to the number of papers from a researcher that has, at least, 10 citations each [21].

m-Quotient. Hirsch, the creator of h-index, proposed in 2011 his own improvement to the famous index. The m-quotient is based on the h-index, which is divided by the number of years since the first publication of an author [17].

Crown-Indicator. Proposed by Centre for Science and Technology Studies at Leiden University, this index is also known as field citation score (Joshi 2014). It considers only the citations from publications by a researcher or a group of researchers that can be equivalent to the world average of citations of works at the same time span, document type, subject area and age, configuring as a subset of comparable works. For instance, if the Crown-indicator of a paper is 0.8, that means this article has 20% less citations than the average. And if a paper has a Crown-indicator of 1.1, that means that this paper has 10% more citations than the average of other papers that fit the same criteria [4].

Author Impact Factor. In 2014, Pan and Fortunato [22] proposed the Author Impact Factor given by "AIF of an author *A* in year *t* is the average number of citations given by papers published in year *t* to papers published by *A* in a period of Δt years before year *t*". This metric is another proposal to overcome the h-index issue of researchers that are no longer actively working, but have kept a high h-index score over several years.

PageRank Index. This index was proposed in 2015 by Senanayake [23]. In order to calculate its value, it is required to analyze a citation network by using the Google's PageRank algorithm. The higher the PageRank, the more relevant the article is.

h_α-index. Hirsh [24], in 2019, proposed the hα-index to quantify an author's leadership. Its value is obtained considering the same papers used to calculate the h-index, i.e. it is a counter. In other words, the hα-index is the number of papers where an author is the main contributor of the paper.

The aforementioned indexes focus on evaluating an individual researcher, more specifically his/her productivity, and also how relevant a certain set of publications is. One of the most relevant indexes, the h-index has variations to evaluate groups of researchers. Some of the proposals to extend the h-index to evaluate a group of researchers are shown in the following.

h_1 index. Mitra in 2006 [11] proposed two extensions of h-index to evaluate research institutions. The first one, the h_1-index corresponds to $h_1 = h$ when the institution has published h papers, with at least h citations each. As long as the h-index has as an input of papers of a given author, the same idea is used by Mitra to evaluate an institution. This is a very simple metric that can be easily applied. However, as for the h-index, when the publication is an effort of two or more institutions, the same paper is integrally counted for both of them.

h_2 index. The second index proposed by Mitra [11] is the h_2 index. This metric takes into account the already calculated h-index of each researcher and gives an idea of the top individuals from some institution. In this scenario, an institution possesses an h_2 index = 1 if one of its researchers has an h-index of 1, another institution has an h_2 index = 2 if two of its researchers have an h-index of 2, …, and, consequently, an institution will have an h_2 index = 20 when 20 of its researchers have an h-index of at least 20, and so on. However, this index can be biased by one group of researchers of the same institution that publish altogether, since in this case the same papers will be considered two or more times in the calculation.

Successive h-indices. It is a model for successive h-indexes proposed by Shubert in 2007 [15]. An author's h-index is calculated by using his/her number of papers and citations. In an institutional level, the idea is to use the h_2-index proposed by Mitra. For higher levels, e.g. a whole region or country, the same idea based on the h_2-index of the lower levels is applied. The modeling of successive h-indexes proposed that a country can be represented by the h_2-indexes of its institutions, e.g. with that approach being applicable in many different levels.

CP-Index. Proposed by Altmann et al. in 2009 [19]. It is based on the RP-Index. The CP-Index is defined as "the largest natural number *y* such that the top *y* researchers of this research community have at least in average a value of *y* for their RP-Index, given that the researchers are sorted according to their RP-Index in decreasing order". It is similar to the Successive h-index model, but instead of being based on the h-index of the researchers, it uses its own RP-Index metric.

(h_2/h_1)-Ratio. Proposed by Rousseau et al. in 2010 [25]. In this paper, the authors highlight that the indexes proposed by Mitra [11] can be calculated in different ways: either considering all the papers of a given author, or only the ones that possess the institutions address in the body of the paper. They also point that two institutions with the same h_2-index might have very different profile of publications. Besides, authors with medium h-index might feel not valued in their institutions. They proposed then dividing h_2/h_1 in order to give a structural indicator of the institution.

The h-index and other standard bibliometric indicators for chemistry research groups was compared by Raan in 2006 [26]. In order to apply h-index for groups, he used all papers of the research group. The study was performed for 147 chemistry research groups in Dutch universities. The study observed a correlation between h-index and citation, however for smaller groups with "less heavy citation traffic" the crown indicators were considered more appropriate.

In 2009, Jacsó [12] applied the h-index for South American countries in Web Of Science and Scopus. He compared the top 10 rank h-indexes of universities in both databases. The study considered that the h-index for groups in Scopus and Web of Science was robust, since both ranks showed almost the same results, except for one position.

An application of h-index average was proposed by Rad et al. in 2010 [13] to evaluate research in radiology. In this study, they selected radiology programs and obtained the h-indexes and the numbers of citations and publications for selected radiologists. They performed a regression analysis to determine which variables were best associated with the academic ranking. A correlation was identified between unrated growth and the h-index of the institution's researchers.

Another application of h-index average to evaluate neurosurgery departments was performed by Khan et al. in 2013 [14]. They evaluate the h-index average by considering sex, academic rank, years of practice, subspecialty, and institution. Their conclusion is that the h-index average can distinguish productivity for academic rank, subspecialty and years of practicing. They also point out that the application of h-index average is not reliable to compare neurosurgery departments.

In this section, we presented several indexes to evaluate a researcher, as well as h-index variations to evaluate research groups, by showing different applications and results accordingly to each field. In the next section we present the challenges and opportunities for measuring groups of researchers.

4 Discussion

This chapter is divided in two sections. In the first one, we present the challenges identified by means of analyzing the current proposed indexes. In the second section, we point out opportunities for evaluating research groups.

4.1 Challenges for Evaluating Groups of Researchers

The h-index is the most popular metric to combine quantitative and qualitative aspects for scientific evaluation of research productivity. The main idea behind it is very simple and practical. It provides a number that combine a quantitative measure assessed of productivity with the relevance of the work according to the number of citations received by it. However, even being a very useful index, a few issues have been brought to light in the last years.

One of the first issues is related to the "quality versus quantity" problem. Authors that are focused on survey papers can have a higher number of citations than others that are producing novel knowledge. The most relevant index to overcome this issue is the Crown-indicator, which only considers papers identified as equivalent by certain characteristics, such as: area of application, publication type, publication period, among other aspects, in order to provide a fairer comparison.

Another issue related to h-index is that an author could have a very high h-index even after years of his/her retirement, while new researchers with new contributions might be hampered, even when presenting quality and quantity in a still short career. Consequently, a few indexes were proposed to overcome this problem, by means of using a time gap to take papers into account, such as the AIF metric [22].

Authors with very different number of papers and citations can have the very same h-index, so the use of self-citation to boost their h-indexes also has become a relevant issue. Indeed, the h-index in certain fields does not represent quite well the reality. A few indexes were proposed by applying a mathematical transformation on the h-index, such as considering citations on squared values [6, 27].

When addressing the evaluation of groups, many other problems become clear. The first one is related to which articles should be used to calculate the indexes. Many proposals focus on the institutional level and so, consider all the papers of a given institution. However, it is not clear if all the papers of each research of the institution are considered, or if there is any kind of special processing for the papers of some researcher who possesses multiple ties or who has changed his/her workplace over the years. This question is important to be considered in the variations of the h-index applied to groups: h_1-index, successive or average, since all of them depend on a set of papers as an input.

Other relevant issue not addressed in the previous works is the strength of a group as a whole. The works focus on institutions or university departments, but not on two or three researchers that are producing science together. There is somehow a union of separated parts and not a whole group. Some recent works use co-authorship [28, 29] and co-citation [30] metrics to evaluate groups of researchers. However, these works focus on analyzing specific areas, not in providing an index to evaluate the scientific weight or value of a group.

In the next section, we present some opportunities to overcome these issues.

4.2 Opportunities for Evaluating Groups of Researchers

Based on the issues highlighted in the last section, it is possible to observe that some of the gaps pointed out in the existing indexes have already been overcome. However, we believe that one of the most remarkable issues is related to the evaluation of the prestige, quality and quantity of the knowledge production of a group of researchers based on their publications.

Scientific papers and even projects usually are an effort of many people. It is commonplace to evaluate new proposals of research projects based on the fundamentals and criteria related to the project itself. Thus, when several project proposals are well formulated a new set of more objective criteria must be used, in order to provide a fairer evaluation. New measures must take into account the number of researchers, the quality of their work as a group, and the aspects of each researcher and the lead researcher. Another relevant aspect is how connected the researchers in this group are, or how linked their research fields are. These questions are important for evaluating research projects and defining, based on the objectives, which group are more suitable for each line of work.

As for future work, we intend to propose new metrics to evaluate: 1) How scientifically relevant a research group is, by proposing a single metric to evaluate both productivity and quality of a group of researchers, when considering their work together; 2) How strong is the connection from one researcher to another, so that is possible to estimate how close their research fields are. Consequently, the idea is to assess whether a group is more likely to become a joint effort in the same field, or an innovative group by merging two or more initiatives from different fields, and; 3) A new different metric for a group of researchers that combine two aspects: how relevant a scientific group is and how strong their connection as researchers is.

In this chapter, we presented the most relevant challenges and opportunities. Moreover, we talked about how the indexes have evolved to overcome the h-index limitations. Finally, we envisaged the proposition of new possible future metrics to overcome the issues presented in the evaluation of a group of researchers. The paper's conclusions are presented below.

5 Conclusions

In this work we presented and discussed the main indexes to evaluate the productivity of a researcher, in qualitative and quantitative ways. First, we summarized the literature review in a table, evidencing how each index is comprised and organizing them into two big groups: (i) the ones that evaluate a single researcher and (ii) others that apply the h-index in different ways to evaluate groups of researchers.

Based on the review of literature, we analyzed three different ways to expand the h-index for the group evaluation scenario: using all of the institution's work, averaging the h-index, and applying the successive h-index approach. Then, we pointed out some challenges to evaluate groups of researchers, such as self-citations and the difficulty in select which papers should be used to evaluate groups in an institutional level, considering that a researcher can change his/her place of work and also have more than one affiliation.

In the end, we also identified some opportunities for assessing research groups, such as evaluating small groups of researchers who work together and considering how linked they and their research fields are among themselves. This is an ongoing work and the opportunities addressed earlier are being worked on and will be more detailed in experiments to be presented in future works.

References

1. Hirsch, J.E.: An index to quantify an individual's scientific research output. Proc. Natl. Acad. Sci. **102**, 16569–16572 (2005). https://doi.org/10.1073/pnas.0507655102
2. Egghe, L.: Theory and practise of the g-index. Scientometrics **69**, 131–152 (2006). https://doi.org/10.1007/s11192-006-0144-7
3. Zhang, C.-T.: The e-Index, complementing the h-index for excess citations. PLoS One **4**, (2009). https://doi.org/10.1371/journal.pone.0005429
4. Joshi, M.A.: Bibliometric indicators for evaluating the quality of scientific publications. J. Contemp. Dent. Pract. **15**, 258–262 (2014). https://doi.org/10.5005/jp-journals-10024-1525
5. Kosmulski, M.: A new Hirsch-type index saves time and works equally well as the original h-index. ISSI Newslett. **2**(3), 4–6 (2006)
6. Flatt, J., Blasimme, A., Vayena, E.: Improving the measurement of scientific success by reporting a self-citation index. Publications **5**, 20 (2017). https://doi.org/10.3390/publications5030020
7. Hirsch, J.E.: An index to quantify an individual's scientific research output that takes into account the effect of multiple coauthorship. Scientometrics **85**, 741–754 (2010). https://doi.org/10.1007/s11192-010-0193-9
8. Valles, M., Injante, R., Hernández, E., Riascos, J., Galvez, M., Velasco, J.: An altmetric alternative for measuring the impact of university institutional repositories' grey literature. In: Mugnaini, R. (ed.) DIONE 2020. LNICST, vol. 319, pp. 222–234. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-50072-6_17
9. Torres-Salinas, D., Robinson-Garcia, N., Jiménez-Contreras, E.: Can we use altmetrics at the institutional level? A case study analysing the coverage by research areas of four Spanish universities, p. 8 (2016)
10. Rousseau, R., Yang, L., Yue, T.: A discussion of Prathap's h2-index for institutional evaluation with an application in the field of HIV infection and therapy. J. Informetr. **4**, 175–184 (2010). https://doi.org/10.1016/j.joi.2009.11.007
11. Mitra, P.: Hirsch-type indices for ranking institutions scientific research output. Curr. Sci. **91**, 1439 (2006)
12. Jacsó, P.: The h-index for countries in web of science and scopus. Online Inf. Rev. **33**, 831–837 (2009). https://doi.org/10.1108/14684520910985756
13. Rad, A.E., Brinjikji, W., Cloft, H.J., Kallmes, D.F.: The h-index in academic radiology. Acad. Radiol. **17**, 817–821 (2010). https://doi.org/10.1016/j.acra.2010.03.011
14. Khan, N., Thompson, C.J., Choudhri, A.F., et al.: Part I: the application of the h-index to groups of individuals and departments in academic neurosurgery. World Neurosurg. **80**, 759–765.e3 (2013). https://doi.org/10.1016/j.wneu.2013.07.010
15. Schubert, A.: Successive h-indices. Scientometrics **70**, 201–205 (2007). https://doi.org/10.1007/s11192-007-0112-x
16. Agarwal, A., Durairajanayagam, D., Tatagari, S., et al.: Bibliometrics: tracking research impact by selecting the appropriate metrics. Asian J. Androl. **18**, 296 (2016). https://doi.org/10.4103/1008-682X.171582

17. Gasparyan, A.Y., Yessirkepov, M., Duisenova, A., et al.: Researcher and author impact metrics: variety, value, and context. J. Korean Med. Sci. **33**, (2018). https://doi.org/10.3346/jkms.2018.33.e139
18. Jin, B., Liang, L., Rousseau, R., Egghe, L.: The R- and AR-indices: complementing the h-index. Chin. Sci. Bull. **52**, 855–863 (2007). https://doi.org/10.1007/s11434-007-0145-9
19. Altmann, J., Abbasi, A., Hwang, J.: Evaluating the productivity of researchers and their communities: the RP-index and the CP-index, p. 15 (2009)
20. Schreiber, M.: A case study of the modified Hirsch index h_{m} accounting for multiple coauthors. J. Am. Soc. Inf. Sci. Technol. **60**, 1274–1282 (2009). https://doi.org/10.1002/asi.21057
21. Kozak, M., Bornmann, L.: A new family of cumulative indexes for measuring scientific performance. PLoS ONE **7**, (2012). https://doi.org/10.1371/journal.pone.0047679
22. Pan, R.K., Fortunato, S.: Author Impact Factor: tracking the dynamics of individual scientific impact. Sci. Rep. **4**, 4880 (2015). https://doi.org/10.1038/srep04880
23. Senanayake, U., Piraveenan, M., Zomaya, A.: The pagerank-index: going beyond citation counts in quantifying scientific impact of researchers. PLoS ONE **10**, (2015). https://doi.org/10.1371/journal.pone.0134794
24. Hirsch, J.E.: hα: an index to quantify an individual's scientific leadership. Scientometrics **118**, 673–686 (2019). https://doi.org/10.1007/s11192-018-2994-1
25. Ye, F.Y., Rousseau, R.: Probing the h-core: an investigation of the tail–core ratio for rank distributions. Scientometrics **84**, 431–439 (2010). https://doi.org/10.1007/s11192-009-0099-6
26. van Raan, A.F.J.: Comparison of the Hirsch-index with standard bibliometric indicators and with peer judgment for 147 chemistry research groups. Scientometrics **67**, 491–502 (2006). https://doi.org/10.1556/Scient.67.2006.3.10
27. Egghe, L.: Theory and practise of the g-index. Scientometrics **69**, 131–152 (2006). https://doi.org/10.1007/s11192-006-0144-7
28. Affonso, F., Dias, T.M.R., de Oliveira Santiago, M.: A strategy for co-authorship recommendation: analysis using scientific data repositories. In: Mugnaini, R. (ed.) DIONE 2020. LNICST, vol. 319, pp. 167–178. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-50072-6_13
29. Fernandes, D., David, N., Cortinhal, M.J.: A distributed tool for online identification of communities in co-authorship networks at a university. In: Mugnaini, R. (ed.) DIONE 2020. LNICST, vol. 319, pp. 179–189. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-50072-6_14
30. Marcelino, L.V., Pinto, A.L., Marques, C.A.: Intellectual authorities and hubs of green chemistry. In: Mugnaini, R. (ed.) DIONE 2020. LNICST, vol. 319, pp. 190–209. Springer, Cham (2020). https://doi.org/10.1007/978-3-030-50072-6_15