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A citation iteration method for publications and scientists evaluation

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ABSTRACT

In the last decades many methods have been developed for the evaluation of the quality and impact of both the scientific research papers and scientists. Effectively identifying, discovering, and evaluating high-impact papers using scientometric methods, and adopting reasonable evaluation procedures and methods are vital to stimulating scientists' creative vitality. Examples of methods used for evaluating impact are: h-index and the cited frequency of articles and the number of highly cited papers. Here we propose a new method to assess the scientist impact based on citation iteration. The method was inspired in the PageRank algorithm. In the present study, both the number of citations and the citing publications after each citation were considered. According to the obtained results, the proposal allows a more accurate measurement of the impact of scientific papers. Also, the application of this method, it can greatly improve the judgment efficiency of high-impact scientists. We have also conducted an empirical study at three levels in the discipline of mathematics, namely the comparisons of two publications, two scientists and eight scientists. Results show that indexes proposed in this dissertation designed for the publications' impacts evaluation and scientists' impact evaluation can be used to find the cause behind the number of cited frequencies resulting in the impact difference. The *Q*-index for publications' impacts evaluation and F-index for scientists' impacts evaluation proposed in this article can be used more accurately to check and evaluate the impact of scientists. Additionally, these new indexes can be used in the research management of departments at all levels, and can be useful by the states to find leading scientists in several fields.

KEYWORDS

Scientist; Evaluation; Citation network; Algorithm; Scientometric Method

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Introduction

Evaluation of scientists has a long history and it is significant for stimulating the innovative vitality of scientists, research institutions, universities and innovative companies. The methods for evaluating the performance of scientists can be divided into two types: qualitative and quantitative methods. The evaluation might be different depending on the applied method (Martin & Irvine, 1983). Overall, we need efficient methods to identify, discover and evaluate high-level scientists. There are at least three ways to optimize these methods. The first one is based on the number of highly cited papers. It is crucial to distinguish subject specificity. The second way is the link-based method to observe the position of a scientist in scientific networks, such as citation or collaboration network. Finally, the last one is the award-winning new evaluation paradigm based on artificial intelligence and machine learning. These have a revolutionary impact which requires high attention and intensive research (Liu & Chen, 2019).

Based on the link-based method, this paper proposes a new iterative method to evaluate the performance of scientists. The algorithm presented is based on the idea of PageRank one. It is a system for ranking webpages developed by Google and it is used to give each page a relative score of importance and authority by the evaluation of the quality and quantity of its links (Brin & Page, 1988). Its advantage comparing to other methods consists in that it takes into account the time factor and it is easier to understand. Our scientometric method follows the citation iteration and add the time dimension to construct a dynamic evaluation index system, which can reveal the difference of impact of the paper based on the impact of citing publications from different citation generations. The proposal uses a non-linear calculation and takes into account the number of cited papers and their impact.

Overall, the methods for scientist's evaluation are divided into two categories: qualitative and quantitative approachs. Peer review is good example of the qualitative methods. With the development of the Internet era, open peer-review has emerged as an attractive alternative for the journals. It includes several alternatives: pre-open peer-review (revision before publication of the article), post-open peer-review (review after publication) and community peer review (Hodgkinson & Dunckley, 2007).

The quantitative method can be summarized in four categories: single indicator, multi-indicator synthesis, link-based methods and altmetrics (Liu & Chen, 2019). Single indicator, include three different types: derived indexes of the h-index (such as g-index, f-index and t-index), those that consider discipline or collaborators disciplines (such as hf-index and n-index), and indexes considering collaborators (such as hp-c index, Hp index and Hm index). A previous research has shown that a single indicator is not a universal indicator, but it must be carefully adopted considering to context and concrete state in that the scientist evaluation is carry out (Wainer & Vieira., 2013). The aim of the multi-indicator method is to construct a comprehensive evaluation index system. Some typical cases were carried out by Costas et al. (2010), Ye (2014), and Abramo et al. (2015). Link-based methods included PageRank, HITS and their variants. Altmetrics is an evaluation method emerging in recent years, which is characterized by the diversity, immediacy and non-traditionality. Its main data sources are ImpactStory, Plum Analytics, PLOS, and Altmetric.com (Chamberlain, 2013). This method was successfully applied by Kousha and Thelwall (2015) in evaluating books and Chen et al. (2015) in social sciences and the humanities. These authors found it helpful to use Altmetric indexes.

PageRank algorithm was originally used for the purpose of page ranking by Google (Brin

& Page, 1998). PageRank is also used in the field of scientometrics as a complementary method to citation analysis, enabling us to identify author impact from a new perspective. For example, Yan and Ding (2011), Radicchi et al. (2009) and Fiala & Tutoky (2017) used the PageRank method to rank scientists.

Data and methods

Data

The discipline of mathematics was selected in this study, since it is a discipline in which the papers have a long half-life. Thus, significant changes in the impact of publications occurs in a relatively long-time scale.

The data used were peer-reviewed papers written by eight scientists who were selected as ESI highly cited researchers in mathematics from Chinese mainland in 2018 by Clarivate Analytics. (We hid specific names and replace them with letters). The source of data was Web of Science, data were downloaded on May 2019. Publication years of the data set range from 2008 to 2019.

Methodology

Here we have used a non-linear iterative method. The impact of each paper was calculated by the impact of the publications that citing it and the paper itself. In addition to considering the number of papers and frequency of citations written by scientists, the impact of the papers was also took into account. The impact of papers was obtained by iterative calculation based on the quality of the citing publications. Thus, the citations from high-impact papers has a greater contribution to the score of the cited papers. The journal's impact factor is added in the calculation as a multiplier for evaluation. As a result of the application of our method, two papers published in the same journal and with the same number of citations, could result with quite different impacts. Moravcsik believes that the impact of a publication lies in its impact on subsequent publications, and this impact will be manifested by the act of citing this publication (Moravcsik, 1977).

Resuming, we have used the following elements to evaluate the scientist: the impact of citing literature, the journal's impact factor and a bipartite network Scientist (Author) and publications

For calculation of the paper impact, we introduce the Q-index. It is defined by the formula:

$$Q = \begin{cases} [IF]^{1-n} \cdot \sqrt[m]{\left(\sum_{j=1} b_{ji} Q_j^m\right)^n} & n \neq 0 \\ IF & n = 0 \end{cases} \qquad \text{Equation 1}$$

Where n is obtained from:

$$n = \frac{Y_N - Y_P}{A} \qquad \text{Equation 2}$$

Here, Q represents the impact of a publication, b (with elements b_{ji}) is the adjacency matrix of the citation network, b_{ji} is the corresponding element of b, and the value of b_{ji} is either 0 or 1. IF represents the impact factor of the journal. The constant A defining a time window and it is related to the citing half-live of publications in the same discipline. The exponent $1/m$ serves as a scale factor to control the magnitude of the value of the result to a more interpretable level. The parameter n is obtained from the Equation 2, in which Y_N is the year when the we evaluate it and Y_P is the publication year. If in the starting level of the process of calculation of Q, the used literature is not cited we use the impact factor of the journal as its impact, in that case $Q = IF$. In particular, when the publication's impact factor is less than 1, we uniformly set it to 1. Finally, in the first equation, we name internal factor the one on the left side of the multiplication sign and external factor the one on the right.

According to Equation 1 when the publication time of a paper increases, its impact depends more and more on its citing publications, and the weight of the term $[IF]^{1-n}$ decreases. The function of the parameter n is being set as a time characterization. When a paper is just published, Y_N and Y_P are equals and n =0. In that case, Q is exactly equal to the impact factor of the journal.

The number of time window A significantly changes depending on the discipline. For this reason, the scholars intensively discuss how better choosing the most suitable time window for each discipline. Egghe and Rousseau (1988), Glänzel, Schlemmer, and Thijs (Glänzel et al., 2003) point out that for Mathematics, the range of citation time must be greater comparing to other fields. Abramo, D'Angelo, and Di Costa's (Abramo et al., 2010) has shown that for Mathematics, the impact factor IF has a greater predictive effect on the quality of the publication than the number of citations under two years or less; this fact is not so obvious in biology and earth sciences. Sugimoto and Larivie re provided a citation schedule for all major disciplines(Sugimoto & Larivière, 2018). In their study, half-life of all major main disciplines was listed.

Analogous to the calculation of the paper's impact, under the effect of non-linearity, the impact of scientists should be more inclined to those with high-impact papers published. In that case, we define an equation to evaluate the impact of authors as follow:

$$F_j = \sqrt[p]{\sum_{k=1} a_{jk} Q_k^p} \qquad \text{Equation 3}$$

Here, F represents the impact of a scientist, a is the adjacency matrix of the citation network, a_{jk} is the corresponding element value in the matrix, and the value of a_{jk} is either 0 or 1. The parameter p is a proportional coefficient. It is set to control the magnitude of the value of the result to a more interpretable level and it reflects the non-linear effect.

Empirical study and analysis

Parameter Settings

As it was previously mentioned, the half-life parameter (A) is not the same for different disciplines. For publications in the field of mathematics, scholars have made estimations on their half-life (Fang, 2018; Zhong et al., 2011). They reported that publications in this field have a long half-life comparing to others. Mathematics is also the discipline with the largest proportion of journals with half-lives greater than 10 years. Thus, we chose A=20 which is two times the "average" half-life in Mathematics because after a period of two times of half-life or a whole cycle impact of articles most comes from its content. In our study, Y_N = 2019, which was the year in that data were downloaded.

Since the summation operation under the root and the square root operation outside the root in the first equation are not inverse operations, the values of the parameters m and p should be smaller to magnify the difference in impacts between different publications, but too small It will cause the calculation result to reach a large order of magnitude and lose its comparative significance. Therefore, the values of the parameters m and p should be carefully selected.

In general, the value of m should be less than 1, to better distinguish the impact of different literatures, and the value of p should be greater than 1, so that the gap between different authors is not too large, especially for a group of highly cited who already have an academic reputation in a certain subject area, a large gap in impact results is unconvincing.

The recommended range of values obtained through the experiments in this study is: 0.7 $m \leq 0.9$ and $2.0 \leq p \leq 4.0$. In our empirical study of the mathematical disciplines we have used m = 0.8, p = 3.

Comparison of the impact of two publications in Mathematics discipline

In this section, we present the comparison of two publications (scientific papers) in mathematics through the calculation of the impact according to using Equation 1. Their titles are: *New conditions on nonlinearity for a periodic Schrödinger equation having zero as spectrum* (tagged as tag1) and *Infinitely many solutions of quasilinear Schrödinger equation with sign-changing potential* (tagged as tag2). Both papers were published in the Journal of Mathematical Analysis and Applications in 2014. The calculation of impacts of these two publications' first-level citing publication are shown in Table 1.

Table 1 Impacts of first-level citing publications of two publications

tag	Impact score	tag	Impact score	tag	Impact score	tag	Impact score
tag1	1.138	tag1	4.946	tag2	1.058	tag2	1.013
tag1	2.012	tag1	0.912	tag2	0.743	tag2	1.626
tag1	2.184	tag1	2.235	tag2	1.189	tag2	1.183
tag1	2.947	tag1	2.351	tag2	0.729	tag2	2.49
tag1	1.969	tag1	0.729	tag2	0.729	tag2	0.75
tag1	4.28	tag1	4.295	tag2	1.483	tag2	0.907
tag1	0.757	tag1	0.971	tag2	4.576	tag2	1.365
tag1	0.743	tag1	1.398	tag2	4.324	tag2	0.483
tag1	0.743	tag1	0.847	tag2	0.931	tag2	0.783
tag1	3.269	tag1	0.972	tag2	1.898	tag2	0.929
tag1	1.17	tag1	1.631	tag2	1.867	tag2	0.369
tag1	1.524	tag1	1.972	tag2	0.962	tag2	1.135
tag1	0.84	tag1	0.948	tag2	4.573	tag2	1.637
tag1	4.483	tag1	0.716	tag2	0.972	tag2	0.453
tag1	2.135	tag1	0.352	tag2	1.488	tag2	0.328
tag1	4.576	tag1	0.574	tag2	1.055	tag2	0.832
tag1	1.79	tag1	0.757	tag2	1.87	tag2	2.105
tag1	1.488	tag1	1.178	tag2	3.637	tag2	0.854
tag1	2.688	tag1	0.925	tag2	0.948	tag2	1.637
tag1	4.351	tag1	1.475	tag2	3.142	tag2	0.818
tag1	1.571	tag1	1.008	tag2	1.484	tag2	1.076
tag1	4.583	tag1	1.394	tag2	1.684	tag2	1.51
tag1	4.324	tag1	1.065	tag2	0.752	tag2	0.992
tag1	0.935	tag2	2.491	tag2	1.627	tag2	1.033

If we use this data and Eq. 1, the values of Q-index are 4.412 (tag 1) and 4.195 (tag 2). The absolute numerical difference between both Q-index is around 5%. As we have reported, in the field of mathematics publications have a long half-life comparing to other. Thus, this numerical difference could be considered relevant and we can say that the publication tag1 is more influential than the publication tag2 in the studied period.

Comparison of the impact of two scientists in Mathematics discipline

In this section, we compare the impact of two scientists who mostly work in Mathematics discipline. We name to them, Scientist X and Scientist Y. Both scientists were selected as highly cited researchers in mathematics from Chinese mainland. Scientist X have 16 highly cited papers while Scientist Y have 9 high cited papers. The impacts of publications of these scientists' and the author's impact (F) calculated by Equation 3 are reported in Table 2. The F-index for these two scientists' are 45.851 (Scientist X) and 35.926 (Scientist Y). The calculated numerical difference (around 22%) clearly indicates that Scientist X have a higher impact than scientist Y according to our methodology.

Table 2 Impacts of two scientists and their publications

tag	Impact of publications (Q)	Impact scores of Author (F)
tag1	4.412	
tag2	4.195	
tag3	1.415	
tag4	3.133	
tag5	1.889	
tag6	7.616	
tag7	2.628	
tag8	4.077	Scientist X: 45.851
tag9	3.071	
tag10	3.165	
tag11	1.986	
tag12	2.738	
tag13	7.896	
tag14	6.312	
tag15	41.792	
tag16	27.950	
tag98	30.986	
tag99	15.748	
tag100	3.481	
tag101	12.760	
tag102	4.115	Scientist Y: 35.926
tag103	4.903	
tag104	4.812	
tag105	1.528	
tag106	21.751	

Comparison of the impact of eight scientists in Mathematics discipline

In this section, we present a generalization of the results reported in Section 3.3, extending the proposed methodology to compare eight scientists who were selected as highly cited researchers in mathematics from Chinese mainland in 2018 by Clarivate Analytics. Scientist are named A, B,… , G, H. The impacts of these eight scientists computed by using Equation 3 are reported in Table 3.

Table 3 Impact scores of eight scientists

Scientist	Impact scores of Scientists	Rank
A	94.884	3
B	60.699	4
C	285.200	1
D	110.277	2
E	45.851	7
F	50.052	5
G	46.649	6
H	35.926	8

Next, let's take a look at which publications have the highest scores and their authors. We will list the top 10 publications with highest impact scores. The results are in Table 4.

Table 4 Top 10 publications for impact score

Scientist	UT number of publications	Publication year	Impact scores	Rank
C	WOS:000253172700040	2008	232.628	1
C	WOS:000257153600005	2008	157.190	2
C	WOS:000260144500003	2008	141.742	3
C	WOS:000252805300009	2008	112.911	4
C	WOS:000207595800007	2008	96.911	5
C	WOS:000261686800038	2008	93.781	6
D	WOS:000263852100003	2009	85.837	7
A	WOS:000256392900040	2008	75.437	8
C	WOS:000264258100011	2008	70.606	9
D	WOS:000259848700034	2008	68.641	10

From the results in Table 4, we can see that the documents with the highest scores have been published for a long time, and scientist C and scientist D are precisely because their highly cited papers were almost all published in 2008, so their impact scores ranked in the top two in this approach.

In addition, scientist A and scientist B have a large number of highly cited papers and these highly cited papers also have high impact scores, so the impact scores of these two professors are ranked forward. Scientist F and scientist G have many publications with a cooperative relationship. In fact, authors of each one of scientist F's highly cited papers included scientist G. Because the approach proposed in this study does not distinguish between the first author and other authors, so scientist F have higher impact score than scientist G.

Compared with three traditional bibliometric method

In order to evaluate the effectiveness of the proposed method we compare our results with three traditional. The indicators selected for the comparative study were the h-index, the cited frequency of articles and the number of highly cited papers. It should be noted that the h-index here is for all the papers of these 8 scientists.

Finally, the comparison results of these four methods are shown in Figure 1.

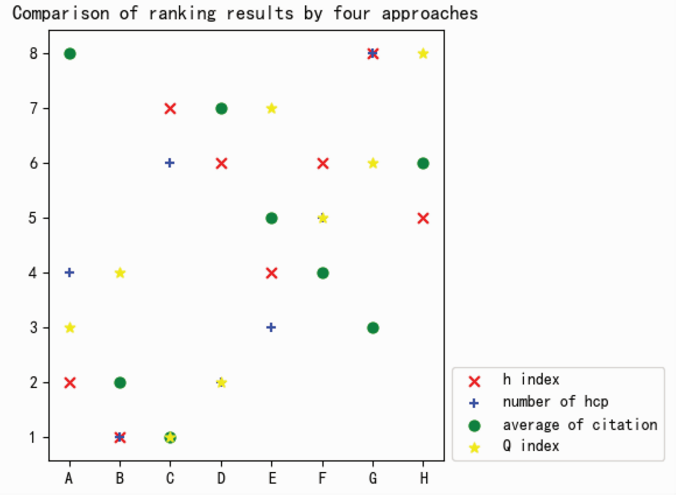

Figure 1 Ranking of 8 Chinese selected authors considering the method used in this work and three traditional scientometric methods (the h-index, the cited frequency of articles and the number of highly cited papers)

Figure 1 shows the ranking results of 8 Chinesse authors calculated by the four scientometric methods. In order to further quantify the difference in the ranking order of the eight scientists under these methods, we use the ranking of each author. The absolute value of the difference is added, that is | DifA | + | DifB | + | DifC | + ... + | DifH |, where the letter A to H represent each scientist, and Dif is the ranking of each scientist under two methods Difference. Under this premise, we need to consider a problem: if two scientists have the same number of highly cited papers, the ranking of them should be the same, such as (6 + 7) /2=6.5... Then, we can't stablish a difference between them.

All calculations are completed and sorted out, and the results are shown in Table 5.

Table 5 Differences in the ranking of 8 Chinese selected authors considering the method used in this work and three traditional scientometric methods

	h index	number of hcp	average of citation	Q index (this work)
h index	/	11	22	24
number of hcp	11	/	24	17
average of citation	22	24	/	20
Q index	24	17	20	/

From the results in Table 5, we can conclude that the method proposed in this research is the closest to that based on the evaluation of high-cited papers, followed by the frequency of citations, and the h-index based on all papers. The evaluation results differ the most. Therefore, we briefly discuss the reasons for this result. It should be pointed out that the number of highly cited papers possessed by each scientist selected by Clarivate is not large. Therefore, the number of highly cited papers data and the h-index data calculated based on the number of highly cited papers are completely consistent (on average, each scientist has 13 highly cited papers, and these papers are easily cited more than 13 times). Therefore, in essence, the ranking result of the method proposed by this research is the closest to the ranking of the h-index calculated by the actual data set, which shows that the method proposed by this research does not run counter to the idea of the h-index, just because it is calculated. In principle, it is more focused on high-cited documents and has a large difference from the h-index ranking calculated by all paper data.

Conclusions

This paper follows the idea of citation iteration and adds the time dimension to construct a dynamic evaluation index system, which can reveal the difference of the paper's quality and impact based on the research of citing publications from different citation generations. The method proposed in this paper uses a non-linear calculation and takes account the number of citing papers and the impact of the citing papers. The study cases carried out at three levels in the discipline of mathematics showed the effectiveness of the citation's impact on the cited literature.

According to our results we conclude that: First, even if the impact factor of the published journal is average, the impact score of a paper can be improved by the further citing papers' impact later. Second, papers published in high impact factors journals could also present lower impact scores. Third, papers published earlier are more likely to gain high impact scores because it has more time to accumulate citing literatures to improve external factors. The last highlight the critical importance to include the time factor in the impact's measurements.

Although this study puts forward a new idea for the evaluation work of publications and scientists and get some meaningful empirical results, it still has certain limitations, which are mainly manifested in the following aspects: first, the full counting method is used in the co-authored article, and the fractional counting method was not considered, and there is no distinction of weights between collaborators. Second, in addition to the impact factors of journals, there may be more appropriate indicators as the initial value (expected value) for newly published papers. Third, this study does not distinguish the motivation of citation.

In future works, we are going to test the validity of the method in a larger data set and expanded the study to other disciplines with different half-life.

It should also be noted that the method proposed in this paper must be limited to a certain application boundary. This study mainly attempts to propose an index to measure the influence of the literature and the influence of the author. The results obtained can only be used as the basic data support for the evaluation of scientists for reference, not the whole. One of the fundamental principles is not to abuse the method, which are just scores, not the whole performance.

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Qiang Liu: Software, Methodology, Formal analysis, Writing - Original Draft, Writing - Review & Editing

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