Do impact factor, *h*-index and Eigenfactor™ of chemical engineering journals correlate well with each other and indicate the journals' influence and prestige?

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This study aims to determine the correlation strength between impact factor (JIF), h-index and Eigenfactor™ of chemical engineering (CE) journals and its subsequent relevance in indicating the influence and prestige of the journals. Five-year JIFs, Eigenfactor™ and Article Influence™ score for the journals are extracted from the 2008 Journal Citation Reports® whereas h-indices are determined from SCImago Journal & Country Rank and ISI Web of Knowledge. It is found that all the aforesaid metrics are highly correlated with one another (Spearman's rho > 0.8) and it is especially true for broad-based CE journals. The Eigenfactor™ and h-index exhibit a power-law correlation and their combination is revealed to be the best indicator of prestige and impact of broad-based CE journals. Findings from this study shed some light on the suitability of the aforesaid metrics to complement each other when used as collective indicators to evaluate the influence or prestige of CE journals or journals of other categories.

Keywords: Chemical engineering, Eigenfactor™ score, *h*-index, journal impact factor, journal influence.

THE most used metric to indicate the relative impact or influence of journals is the Thomson Reuters journal impact factor (JIF). Although the popularity and widespread usage of this metric are never in doubt, it is often criticized for its apparent limitations. These limitations include bias towards journal popularity over prestige[1], its abuse by unscrupulous journal editors[2] and insensitivity to journal self-citations[3]. In addition, it has been known that other article types of lesser significance such as letters to the editor, editorials and notes contribute to the citation counts in the JIF's numerator but not the denominator[4], further inflating its actual value. It is well known within the academic community that JIF can be easily manipulated by journal editors via skewed submission policies (such as inclusion of review articles) in order to increase JIF, which in turn, becomes an instrument used by publishers to market their journals to libraries worldwide. Needless to say, this has brought upon direct undesired overlap of academia and the lucrative publication market, a circumstance often frowned upon within the academia.

In order to circumvent these limitations, numerous alternative journal performance indicators have been introduced. These include the *Y*-factor[1], *h*-index[5], AR-index[6] and Eigenfactor™ score[7]. Of these indicators, the *h*-index and Eigenfactor™ score of ISI-indexed journals can be easily obtained from the World Wide Web and they are therefore useful tools for researchers to determine the relative impact of a journal. The *h*-index is originally intended to quantify an individual's scientific research output and impact in which 'a scientist has index h if h of his or her N_p papers have at least h citations each and the other $(N_p - h)$ papers have $\leq h$ citations each'[5]. It has since been extended to quantify the impact of specific journals such as forestry[8] and organic chemistry[9] journals. In both cases, usage of *h*-index for journals is justifiable since a study conducted by Schubert and Glänzel[10] found that *h*-index is a robust alternative indicator advantageously supplementing JIFs.

On the other hand, the Eigenfactor™ score is a novel indicator that uses an iterative ranking scheme similar to the approach Google™ uses to rank web pages. Eigenfactor™ measures the importance of a citation by the influence of the citing journal divided by the total number of citations appearing in that journal[7] and is already listed in the Journal Citation Reports® (JCR). The Eigenfactor™ developers utilize algorithms that include the structure of the entire network (which includes other interdisciplinary fields and over an extended period of citation windows) instead of purely localized citation information used in other ranking algorithms to assess the significance of

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each journal. The algorithm corresponds to a simple model of research in which the journal audiences follow chains of citations as they move from journal to journal. The Eigenfactor™ score is determined using total publications within a time window of five years. The developers argue that this approach 'corrects for differences across disciplines and journals in the propensity to cite other papers'. There are three main attributes of the Eigenfactor™ score, viz. (i) exclusion of journal self-citation in its calculation; (ii) high emphasis for citations from original works published in top-tier journals such as *Nature* or *Science* and (iii) subscription to the concept of large network of citations. This is further elucidated in the website of the Eigenfactor™ creators (http://www.eigenfactor.org/methods.htm).

A recent study[11] reports that there is a strong correlation between Eigenfactor™ and the total number of citations received by a journal. Both the *h*-index and Eigenfactor™ deserve further evaluation as alternative metrics to supplement JIF. A brief preliminary study conducted reveals a tendency for these two metrics to indicate journal influence or prestige. As such, the author hypothesizes that this observation may be similar in the case of chemical engineering (CE) journals. Besides that, the relationship or correlation between the three aforementioned metrics has yet to be comprehensively analysed and this provides the main question that this study attempts to answer. Such study will shed light on the suitability of the three metrics to complement each other when used as collective indicators to evaluate the influence or prestige of CE journals or journals of other categories for that matter.

Methodology

The five-year journal impact factors (5-year JIF) (dividing the number of citations in 2008 by the total number of papers published from 2003 to 2007), Eigenfactor™ and Article Influence™ (AI) scores for the journals were extracted from the 2008 JCR (obtained from ISI Web of Knowledge℠) whereas the *h*-indices were obtained from SCImago Journal & Country Rank[12] (retrieved on 19 June 2009). It should be noted that 5-year JIF was used instead of the latest impact factor because the former provided a more encompassing value that reflected the mean impact factor throughout several years. The Eigenfactor™ scores were also calculated using similar five-year time window. Only journals listed in the category 'chemical engineering' in the 2008 JCR were analysed in this study. Selected CE journals without all the four aforesaid metrics were excluded from the study. In summary, 104 CE journals were selected. The correlations among 5-year JIF, *h*-index, Eigenfactor™ and AI scores of the CE journals were quantified using Spearman's rank-order correlation[13] analysis.

Results and discussion

All CE journals

The sample of 104 CE journals shows mean values of 1.40 (5-year JIF), 23.88 (*h*-index), 0.0081 (Eigenfactor™) and 0.4091 (AI score) as well as standard deviation values of 1.29 (5-year JIF), 17.68 (*h*-index), 0.0133 (Eigenfactor™) and 0.4347 (AI score) respectively. Figure 1 shows the individual correlations among 5-year JIF, *h*-index, Eigenfactor™ and AI score of all CE journals. In terms of macrolevel, it can be seen that all four metrics are highly correlated with one another since their Spearman rank-order correlation coefficients (rho) are higher than 0.8. Nonetheless, visual observation indicates that outliers are largely present in the *h*-index versus 5-year JIF and Eigenfactor™ versus 5-year JIF curves. It can be observed that these outliers are generally journals that have a narrow scope of CE research themes. Three catalysis-based journals (*J. Catal.*, *Catal. Today* and *Appl. Catal. B-Environ.*) as well as *Prog. Energy Combust.* are examples of CE journals with narrow CE research scope.

The highest rho value of 0.9626 is determined between the AI score and 5-year JIF. This is hardly surprising since it has been stated by Bergstrom[7] that AI score is 'directly comparable' to JIF. A journal's AI score is basically a quantification of the average influence of each of its articles over the first five years after publication. The AI score is normalized with respect to a mean of 1.00; therefore a journal with a JIF of 10 has more than 10 times the influence of the mean journal in Thompson Scientific's ISI database[7]. The rho value of 0.9139 determined between Eigenfactor™ and *h*-index is also considered very high. Since both rho values are higher than 0.9, it is justifiable to determine their R^2 values as well. It is rather obvious that empirically, AI score and JIF have a linear correlation whereas Eigenfactor™ and *h*-index exhibit a power-law correlation. These empirical correlations are expressed in the following

$$\mathrm{AI} = a\mathrm{JIF}, \tag{1}$$

$$E = bh^{c}, \tag{2}$$

where E is the Eigenfactor™ score; h is the *h*-index and a, b and c are constants determined empirically to be 0.3062, 1×10^{-5} and 1.7921 respectively. In terms of statistical analysis, the p- and ANOVA significance F values are determined to be less than 0.01 for all the constants. It is interesting to note that Eigenfactor™ and *h*-index also seem to exhibit a quadratic correlation as well. However, further analysis indicates that the p-values for the quadratic constants are higher than 0.01, implying that quadratic correlation is not suitable for this case.

The group of 104 CE journals may not provide an entirely accurate representation of the correlation

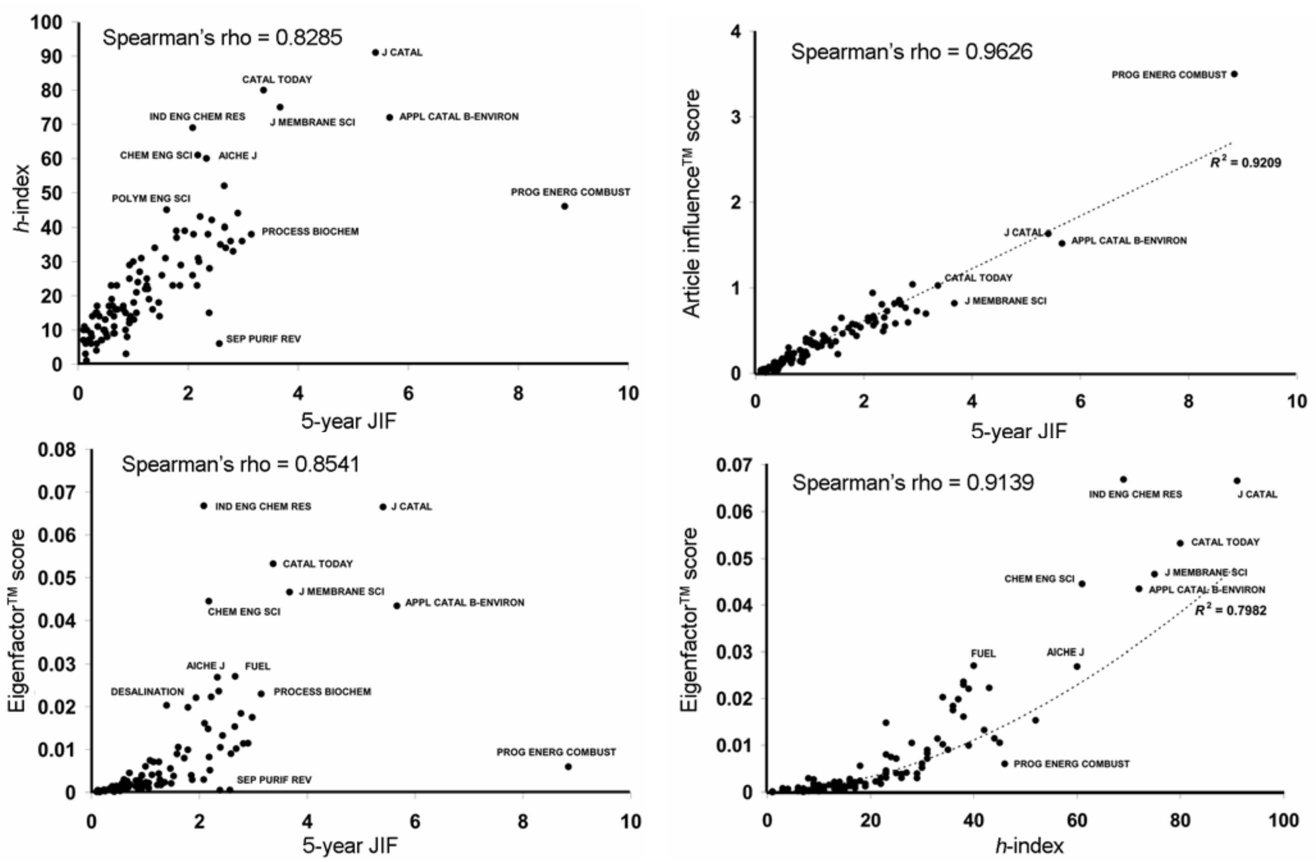

Figure 1. Correlations between 5-year JIF, *h*-index, Eigenfactor™ and Article Influence™ score of all chemical engineering journals (total = 104).

between the metrics simply because most of the journals are listed in other categories other than 'chemical engineering' in JCR (though it is still necessary to conduct an analysis of all the CE journals for comparison purposes). A brief inspection of JCR reveals that many of these CE journals are in fact, multidisciplinary in nature and listed in categories such 'physical chemistry', 'energy' and 'environmental engineering' as well. Such listing complicates the bibliometrics analysis and may cause elevated metrics values due to infusion of research output of other disciplines as in the case of the catalysis-based journals.

Broad-based CE journals

In order to further refine and provide a more accurate representation of CE journals, the analysis is repeated, but only broad-based CE journals are considered. For this case, broad-based CE journals with multiple category listings (i.e. only listed in the category 'chemical engineering') and those that publish only review papers are excluded. These journals are basically defined as journals that publish a wide range of CE-themed research studies (e.g. reaction engineering, separation processes, catalysis, process safety, etc.) rather than focusing on just one theme. In this analysis, 15 broad-based CE journals are considered. Three of such journals, viz. *Ind. Eng. Chem. Res.*, *Chem. Eng. Sci.* and *AIChE J.*[14,15] are generally considered as the most prestigious broadbased CE journals within the CE academia. To further support this statement, the author conducted a simple bibliometric analysis on the broad-based CE journals preferred by CE researchers from top academic engineering institutions. The analysis sample includes the top 10 engineering schools ranked by the 2009 THES World University Ranking, viz. the Massachusetts Institute of Technology, University of California, Berkeley, Stanford University, University of Cambridge, California Institute of Technology, University of Tokyo, Imperial College London, University of Toronto, Carnegie Mellon University and ETH Zurich. By using Scopus.com as the online database, the name of the academic institution was specified in the search engine under the subject 'affiliation'. The search results were subsequently limited to the subject area 'chemical engineering' (extracted on 22 January 2010). Results indicate that *Ind. Eng. Chem. Res.* (total 561), *Chem. Eng. Sci.* (total 968) and *AIChE J.* (total 264) consistently occupy the top three positions with regards to broad-based CE journals preferred by researchers from the above-mentioned institutions. This directly implies

Table 1. Broad-based CE journals ranked by 5-year JIF, *h*-index, Eigenfactor^{TM} and Article Influence^{TM} score

Broad-based CE journal	5-year JIF	Ranked by 5-year JIF	*h*-Index	Ranked by *h*-index	Eigen-factor^{TM} score	Ranked by Eigen-factor^{TM} score	Article Influence^{TM} score	Ranked by Article Influence^{TM} score
Chem. Eng. J.	2.773	1	36	4	0.01843	4	0.765	2
AIChE J.	2.334	2	60	3	0.02687	3	0.803	1
Chem. Eng. Sci.	2.177	3	61	2	0.04452	2	0.666	3
Ind. Eng. Chem. Res.	2.083	4	69	1	0.06681	1	0.607	4
Chem. Eng. Technol.	1.086	5	24	6	0.00744	5	0.351	6
Chem. Eng. Res. Des.	1.003	6	30	5	0.00606	6	0.368	5
Braz. J. Chem. Eng.	0.863	7	10	10	0.00133	11	0.200	9
J. Chem. Eng. Jpn.	0.703	8	23	7	0.00452	7	0.224	8
J. Chin. Inst. Chem. Eng.	0.645	9	9	12	0.00105	12	0.135	11
Can. J. Chem. Eng.	0.602	10	23	7	0.00301	8	0.226	7
Chem. Eng. Commun.	0.564	11	17	9	0.00206	9	0.175	10
Chinese J. Chem. Eng.	0.464	12	10	10	0.00146	10	0.090	12
Theor. Found Chem. Eng.	0.238	13	6	13	0.00061	13	0.055	13
Asia-Pac. J. Chem. Eng.	0.152	14	1	15	0.00006	15	0.030	14
Chem. Process. Eng-Inz.	0.139	15	6	13	0.00029	14	0.021	15

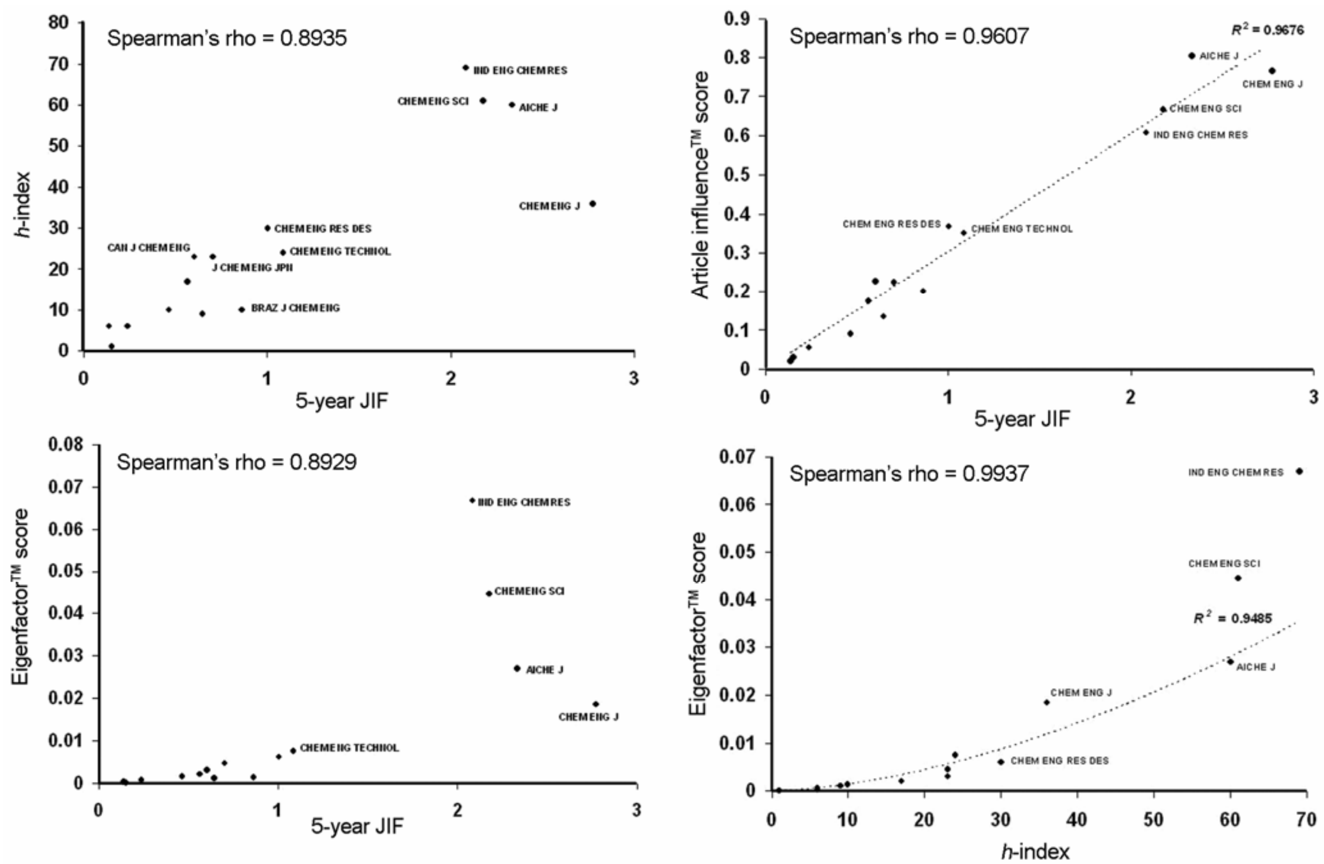

Figure 2. Correlations between 5-year JIF, *h*-index, Eigenfactor^{TM} and Article Influence^{TM} score of broad-based ISI-indexed CE journals (total = 15).

the high prestige of these journals and they are subsequently used as benchmarks to qualitatively determine the effectiveness of the metrics to evaluate journal influence or prestige. A noteworthy journal among the broad-based CE journals is *Chem. Eng. J.* which is ranked fourth (*h*-index) and second in AI score. The reason for its relatively low *h*-index is perhaps its growth in stature in the last few years.

Table 1 lists all the 15 broad-based CE journals which are ranked by 5-year JIF, *h*-index, Eigenfactor^{TM} and AI score. Such a ranking list was previously utilized by Bornmann *et al.*[9], to rank organic chemistry journals. It

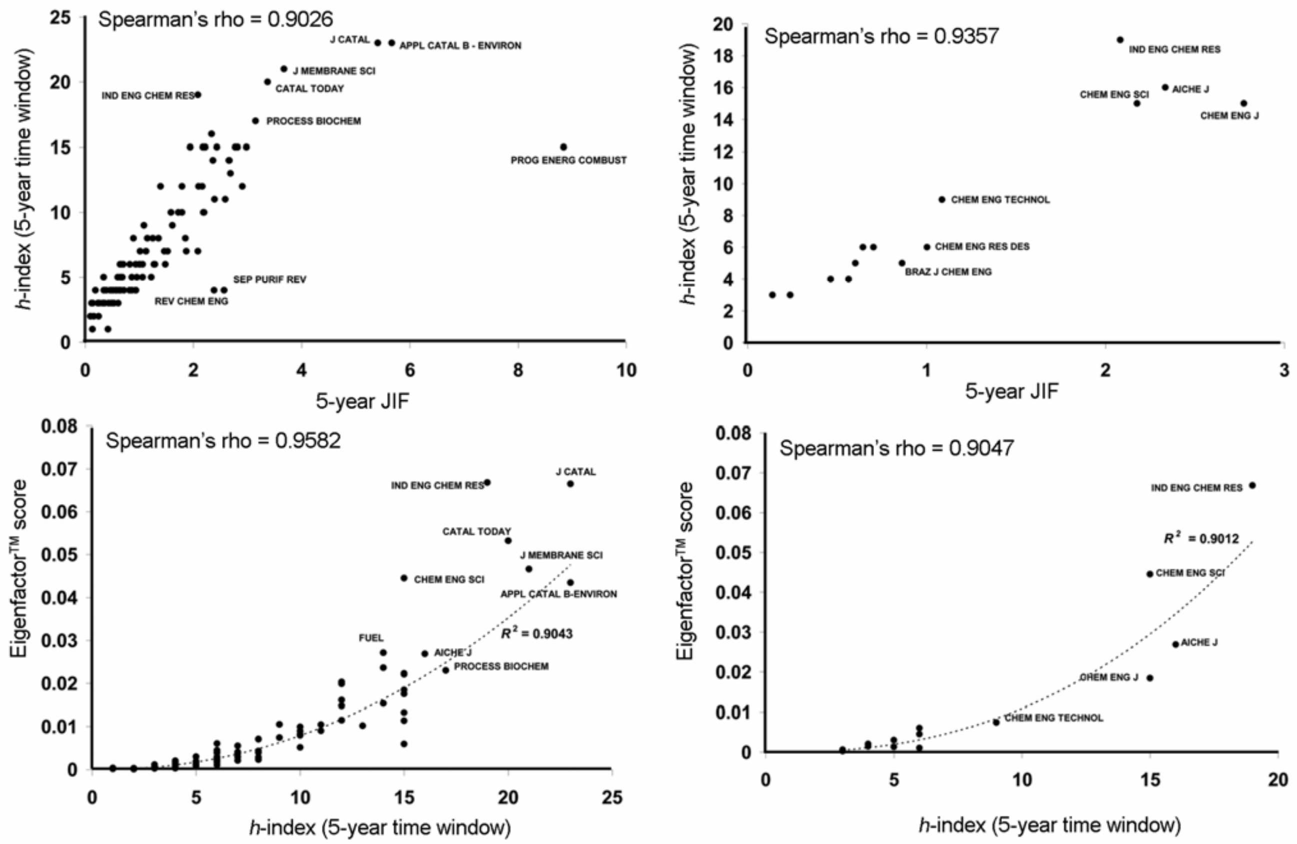

Figure 3. Correlations between 5-year JIF, *h*-index (5-year time window) and Eigenfactor™ score of all (total = 102) and broad-based (total = 14) CE journals.

can be seen that JIF, Eigenfactor™ and AI score are able to rank better between the journals than the *h*-index since the latter is integer-based, an observation somewhat similar to Bornmann *et al.*[9]. Nonetheless, Bornmann *et al.*[9] argue that 'missing precision of integers is not seen by all bibliometricians as a disadvantage' since the *h*-index avoids, as an integer, 'the false impression of precision conveyed by the three decimal points in the ISI impact factor'[16].

Figure 2 shows the individual correlations among 5-year JIF, *h*-index, Eigenfactor™ and AI score of broad-based CE journals. All four metrics are correlated well with one another since their rho values are higher than 0.89. These high rho values are quite possibly attributed to the absence of review journals and exclusion of significant encroachment from other disciplines. In this case, all four metrics seem to be rather robust as indicators for measuring relative impact of broad-based CE journals. As in the section 'All CE journals', AI score and JIF have a linear correlation whereas Eigenfactor™ and *h*-index exhibit a power-law correlation for broad-based CE journals. In this case, a, b and c are determined empirically to be 0.3022, 3×10^{-5} and 1.68 respectively. The p- and ANOVA significance F values are also determined to be less than 0.01 for all the constants.

Adjustment of h-index to within a five-year time window

So far, the *h*-indices do not use a time window similar to the 5-year JIF and Eigenfactor™ (SCImago Journal & Country Rank uses time windows longer than five years). Nonetheless, the previous results are necessary to provide a more comprehensive point of discussion and for comparison purposes. In order to make the *h*-indices comparable to the five-year JIF, the same time window is used to calculate the indices: the publications in the period 2003–2007 and the citations of these publications in 2008 (ref. 17). In actual sense, such time window adjustment enables a more accurate representation of the overall bibliometric analysis. In this case, the 5-year *h*-indices are systematically obtained from the ISI Web of Knowledge℠ search engine by retrieving all source items of a given journal from 2003 to 2007 and sorting them by the number of 'times cited' for 2008. The highest rank number which is still lower than the corresponding 'times cited' value is the *h*-index of the journal[18].

Figure 3 shows the individual correlations among 5-year JIF, *h*-index (five-year time window) and Eigenfactor™ score of all (total = 102) as well as broad-based (total = 14) CE journals. The reduction of sample sizes from 104 to 102 (all CE journals) and 15 to 14 (broad-based CE journals) is attributed to exclusion of journal titles which do not have complete indicator record within the 2003–2007 time window. It seems that all the metrics exhibit higher rho values (with the exception of Eigenfactor™–*h*-index for broad-based journals) after time window adjustment of *h*-index. After the time window adjustment, the power-law correlation of Eigenfactor™ and *h*-index is maintained. In this case, the *b* and *c* values are determined empirically to be 6×10^{-5} and 2.1532 (all journals) as well as 4×10^{-5} and 2.4555 (broad-based journals), respectively. Similarly, *p*- and ANOVA significance *F* values are less than 0.01 for the *b* and *c* constants.

A common trend seen in Figures 2 and 3 is that *Ind. Eng. Chem. Res.*, *Chem. Eng. Sci. and AIChE J.* appear in the top right corner of all the broad-based journals figures, further reinforcing the established notion that these three journals are the most prestigious broad-based CE journals. This observation, in turn, can be used to determine the best combination of metrics for bibliometricians to evaluate prestige of journals. The author suggests that the combination of Eigenfactor™ and *h*-index provides the best indicator of prestige and impact of broad-based CE journals (and this may apply to other scientific journals as well) since the three aforementioned journals have the highest Eigenfactor™ scores and *h*-indices among all the broad-based CE journals.

Conclusions

In summary, it is shown that all four metrics are highly correlated with one another and it is especially true for broad-based CE journals. It is also implied that journals that publish review articles and are of multidisciplinary nature may contribute to the skewness in statistical data of the four metrics. The Eigenfactor™ and *h*-index exhibit a power-law correlation and their combination is revealed to be the best indicator of prestige and impact of broad-based CE journals. The author suspects that such combination may even apply for other scientific journals as well and this warrants future studies involving bibliometricians for respective fields.

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