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The Role of the Journal Impact Factor in Chemistry Research

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Abstract: The journal impact factor (JIF) is a skewed metric whose value is dictated by just a few highly cited articles. Therefore, the use of the JIF to evaluate journals, scholars, or research institutes is flawed. Still, the JIF continues to play a central role in evaluating scholarship in chemistry, the most reluctant amid scientific disciplines to embrace the principles of open science. This study investigates the origins of this social behavior and suggests avenues to improve scholarly communication in the chemical sciences following the example of the life sciences.

Keywords: Chemistry · Chemistry journals · Journal impact factor · Preprint · Scientific publishing

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1. Introduction

The journal impact factor (JIF) was introduced by Garfield and Sher as the ratio between the number of citations in the current year to articles published in a indexed journal in the previous 2 years and the overall number of articles published by the journal in the same previous 2 years.[1] In 1975, Garfield's company (Institute for Scientific Information, USA) started to publish the annual *SCI Journal Citation Reports* containing the JIF values of indexed scientific journals.[2]

'Indexed' means that said articles were included in the *Science Citation Index* (SCI), a cross-disciplinary database launched by Garfield and Sher in 1964 with two purposes: "*first, to identify what each scientist has published, and second, where and how often the papers by that scientist are cited*".[2]

Whoever uses the JIF, wrote Curry in 2012, is "*statistically illiterate*".[3] As shown by Seglen in 1992,[4] indeed, the citation distribution is so skewed that only 15% of the papers in a journal account for 50% of the total citations. This fact makes the JIF a worthless tool to evaluate scientific journals. "*Take a moment to think about what that means*", added Curry, "*the vast majority of the journal's papers – fully 85% – have fewer citations than the average*".[3]

Consequently, evaluation of researchers based on the JIF of journals selected for publication is inherently flawed.[5] Still, evaluation committees worldwide continue to use the JIF to evaluate scholarship based on the aforementioned intrinsically biased metric of 'academic prestige'. Examples span from ongoing use of the JIF in academic review, promotion, and tenure evaluations at 'research-intensive' universities in United States of America and Canada,[6] through the 'uncontested focus on impact factors'[7] for researcher evaluation in Spain.[7]

The "*skewedness of science*"[4] namely the Pareto distribution for which a small percentage of journals account for a large percentage of the articles published in a specific field of science, had been unveiled by Bradford, a mathematician and then a librarian at London-based Science Museum, in 1934.[8]

Displaying a graph reporting the "*cumulative percent of journal items published*" vs. the number of science journals indexed, Garfield, in a video recorded in 1967, emphasized how just 365 journals accounted for over 90% of the articles.[9] This, he concluded, shows evidence of 'Bradford's law'; namely the law of distribution of papers on a given subject in scientific periodicals.[8]

The success of the SCI database, wrote Garfield in 2007, "*did not stem from its primary function as a search engine, but from its use as an instrument for measuring scientific productivity, made possible by the advent of its by-product, the SCI Journal Citation Reports… and its Impact Factor rankings*".[2] Today, from CrossRef through Dimensions, numerous other scientific databases exist that index scientific journals and return the num-

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ber of citations for each of the aforementioned 'journal items published'. What has barely changed since the early days of the JIF, is the rush to academic prestige based on publishing in 'high ranking'(*i.e.* high JIF) journals.

In chemistry research, the JIF has played a critical role, which partly explains why chemistry – from the poor uptake of preprints,[10] through open access (OA) publishing[11] – has been the most reluctant amid the so-called 'basic' scientific disciplines (physics, chemistry, mathematics and biology) to embrace the principles and the tools of open science. One key principle of open science is the global need to improve scholarship evaluation, going beyond the misuse of bibliometric indicators such as the JIF wrongly used to assess scholars.[12,13]

Putting the discussion in context by focusing first on the case of chemistry research, this study investigates the origins of this social behavior. We conclude suggesting avenues to improve scholarly communication in the chemical sciences following the example of the life sciences.

2. The Case of Chemistry Research

Chemistry is unique amid all basic sciences because it has the highest level of publishing market concentration. Between 1973 and 2013, the share of papers published by the top five publishers (Reed-Elsevier, Springer, Wiley, ACS Publishing and Taylor & Francis) has increased from about 40% to >70%.[14] Another key publisher of chemistry research is RSC Publishing, namely the publishing branch of the Royal Society of Chemistry.

In the first three decades of the 21st century, new competitors such as MDPI, Hindawi and Frontiers Media emerged. Two, in particular, MDPI and Frontiers (both based in Switzerland), quickly grew and respectively became in 2022 the world's third and sixth largest scientific publishers by number of published articles.[15]

Academic behavior may also be understood within the context of a prestige (or attention) economy that drives motivation in academic life.[16] As noted by Fyfe and co-authors, after the Second World War large publishing companies learned how to make themselves "*apparently indispensable*"[17] to achieve said academic prestige. In brief, academic careers, including those in the chemical sciences, are chiefly based on highly cited research papers and large number of citations.

In 1973, the percentage of papers published by the five major publishers in chemistry research was already twice as large as that of the other basic sciences (~40% vs. ~20%).[14] In the subsequent four decades, research chemists were unable to escape the academic prestige mechanism driving academic careers,[16] and even increased the percentage of research articles sent for publication to the top five publishers.[14]

In this striving for academic prestige, the JIF of chemistry journals played a key role. The analysis of the 16,378 chemistry articles indexed by the research database replacing the SCI (Web of Science) from 2000–2009, indeed reveals that a unit increase in the JIF corresponds to an increase of the mean citation count by 31.9%.[18] Accordingly, research chemists continued to strive to publish the outcomes of their research in chemistry journals with the highest JIF.

Until the launch of prestigious OA journals such as *Chemical Science* or *ACS Central Science*, the latter high JIF chemistry journals turned out to be the well known, subscription-based journals published by the most concentrated segment of the whole scientific publishing industry.

With 207 journals (indexed by Web of Science) owned by 20 publishers in 2017, indeed, chemistry is the second most concentrated segment (after the multidisciplinary segment with only 15 journals published by 10 publishers).[19] As can be expected from said level of market concentration, with a $7,014 average price for journal subscription in 2022, chemistry has the highest average journal serial cost amid all scientific disciplines (Table 1).[20]

Table 1. Average 2022 journal prices for scientific disciplines (Source: ref. [20]).

Rank	Discipline	Average price per title (in USD)
1	Chemistry	7,014
2	Physics	5,587
3	Engineering	4,596
4	Biology	4,374
5	Food Science	3,745
6	Geology	3,706
7	Technology	3,430
8	Botany	2,994
9	Zoology	2,883
10	Geography	2,666
11	Health Sciences	2,600
12	Agriculture	2,519
13	General Science	2,423
14	Astronomy	2,340
15	Mathematics and computer science	2,322

In 2020, for comparison, the average subscription price to the same journals was $6,316.[21]

Perhaps only in the medical sciences has the JIF been so widely used to evaluate scholars. For example, regardless of its intrinsic lack of value to evaluate journals and scholars due to the aforementioned skewedness of its statistical distribution,[3–5] evaluation committees still encourage candidates to submit applications and publish CVs including the author 'cumulative impact factor' (or cumulative impact index). The index is simply obtained by the sum over all the studies that the author has published of the current JIF of the journals in which the studies were published.

Besides relying on a flawed metric such as the JIF, this metric adds another distortion because it does not refer to the number of citations the candidate's paper has actually received. For example, one candidate may have published a widely cited paper in a journal with a low impact factor, and another candidate a poorly cited paper in a journal with a high JIF. The latter candidate, absurdly enough, would have a higher 'cumulative impact factor'.

3. Early Signs of Change

Today's scientific research takes place in the information economy of the digital age in which "*everything is plentiful – except attention*",[22] Chemistry is no exception. The number of annual publications in chemistry only (without including articles in materials science journals often owned by large chemistry publishers) has more than doubled from 73,974 in 2000 to 158,570 in 2018.[23]

Until the mid 2010s research chemists continued to publish their research findings in 'paywalled' journals in which articles are published online behind a 'paywall' consisting of a single access fee or payment of the subscription costs listed in Table 1. With only ~15% of the overall articles published between 2009 and 2015 being OA, chemistry in 2015 was the discipline with lowest uptake of open access.[24]

Driven by research funding agency mandates requiring funded research to be published as OA articles, however, the share of OA significantly increased in 2017. In 2020, for the first time, more than half (57%) of all research articles indexed in multidisciplinary chemistry journals were openly accessible (same outcome in 2021).[25]

With the exception of a few journals such as the *Beilstein Journal of Organic Chemistry*, *Chemical Science*, *ACS Central Science* and *CHIMIA* where OA publication is free ('platinum' or 'diamond' OA), said articles are made OA by the journal publisher *via* payment of an article processing charge. The journal, furthermore, can be either a 'hybrid' journal publishing both paywalled and OA articles, or a pure 'gold' OA journal publishing OA articles only. Selected examples of the latter are *Molecules*, *ChemistryOpen*, *ACS Omega*, *RSC Advances*, *BMC Chemistry* and *Frontiers in Chemistry*. Certain OA chemistry journals such as *RSC Advances* publish over 5,000 articles in one year, and others less than 100. What matters here is that OA articles in these and many other OA journals today are highly read.

The aforementioned citation advantage for articles published in high JIF chemistry journals during the 2000–2009 decade,[18] is no longer valid for articles published in subsequent, more recent years. For example, Larivière and co-workers analyzed a random sample of 100,000 articles published between 2009 and 2015 in twelve disciplines including chemistry (biomedical research, mathematics, clinical medicine, health, earth and space, biology, physics, psychology, social sciences, professional fields, engineering and technology, chemistry).[24] The team found that papers made OA *via* 'green' self-archiving were cited 33% above the average, while those paywalled were cited 10% below the average. In other words, articles self-archived in personal or institutional websites receive 33% more citations than average.

The same is true for preprints. Chemists preprinting their research found out that citation of preprinted studies came earlier and further increased the overall number of citations of the corresponding peer reviewed article.[26]

In the early 2000s, chemistry preprints posted in the first preprint repository (Chemistry Preprint Server) were "*valued, read, and discussed to a notable extent within the chemistry community*".[27] Unfortunately, only 6% of chemistry journals accepted preprints for peer review[27] and research chemists had to wait until the late 2010s to see preprints accepted for peer review by the editors of the main chemistry journals.[10]

In a few years, a number of new preprint repositories were launched including ChemRxiv, Zenodo, Authorea, Preprints and Research Square. A small fraction of chemistry researchers worldwide started to publish their research papers first in preprint form and then as peer-reviewed articles in widely different journals.[10] Likewise to what happens in all other basic sciences such as physics and biology where most scholars preprint their research, chemists discovered that preprints were widely read (by early December 2022, for instance, the 15,542 preprints posted on ChemRxiv had been downloaded 8,557,101 times)[28] and regularly cited by colleagues.[29] To date the aforementioned 15,542 preprints posted on ChemRxiv have been cited 3,054 times.[28] The latter figure suggests that ChemRxiv has a high JIF,[30] even though the repository is not a peer-reviewed journal.

4. Perspectives and Conclusions

The increasing publication output of chemistry scholars and the growing number of journals publishing chemistry research make it increasingly difficult for papers to attract sufficient attention from the research community. Said information overload, furthermore, leads to a scarcity of attention not only of peer researchers but also of reviewers and journal editors.

For example, "*when authors claim to use a 'fluorescent microscope' you should stop reading*", [31] wrote a scientist on Twitter in late 2022. It is enough to carry out a search on the publications web page of two chemistry publishers with the query 'fluorescent microscope' to respectively retrieve from the RSC and ACS publications websites 1756 and 3159 documents mentioning the 'fluorescent microscope'.[32,33]

Taking into account that in today's information economy era the aim is not 'getting published' but getting read, research chemists need to rediscover the art of writing. This requires the ability to write concise, clear and useful texts, starting from the article's title and abstract.[34,35] Similarly, the effective use of social media (Twitter in particular) to disseminate research findings reported in preprints and peer-reviewed articles provides substantial benefits in terms of research visibility and impact, as well as of learning and collaboration opportunities.[36]

Research chemists willing to enhance the impact of published research papers simply needs to make their articles openly and freely accessible by self-archiving all the studies in a personal academic or institutional website.[37] After a few months, they will find out that the number of citations of their formerly paywalled research papers not only increases, but that papers start to get cited for a longer period than what happens with chemistry research articles published in paywalled journals.[38] The latter (with the exception of review articles) receive a maximum number of citations two years after publication, followed by a quick decrease.[39]

Following immediate publication of research findings in preprint form, today's researchers in the chemical sciences can submit their work for publication following peer review to an unprecedented large number of chemistry journals. Soon, we forecast in conclusion, many of these periodicals may follow the example of the life science journal *eLife* that, starting in early 2023, will no longer adopt the publish/reject publishing model.

The journal, which only accepts preprints for peer review, will publish all articles as Reviewed Preprints. The journal's editors select submitted preprints for review. Following peer review from experts in the field, the reviewed papers will be published on the journal's website as citable Reviewed Preprints. Following publication, the authors decide whether or not to submit a revised version of the study. If revised, the papers are again reviewed and published in an iterative process during which authors can declare that the current version of their paper is the 'version of record'.[40] Each article (Reviewed Preprint) will include on the top of each article page a link to access the reviews "*describing the strengths and weaknesses of the work*", alongside the editors' assessment of the article "*summarising the strength of the evidence*".[41]

On the other hand, counter-evidence suggesting that this may actually not happen originates from the case of *F1000Research*, an online multidisciplinary journal that since 2012 uses a similar model where articles are firstly published like a preprint, and then followed by an open peer review process.[42] As of today (*i.e.*, in 11 years of publishing activity) only 5860 articles were posted in *F1000Research* across the entire scientific spectrum, of which only 160 manuscripts fall in the chemical sciences field.[43]

The comparison with *eLife*, however, is not straightforward. F1000, a for-profit company, was sold to one of the top five scientific publishers in 2020. Likewise the journals of the RSC, on the other hand, the journal *eLife* is published by a non-profit organisation that receives financial support and guidance from charitables and Europe's largest public scientific institution (the Max Planck Gesellschaft). The first journal's editor was a Nobel prize laureate. The journal started publication in late 2012 and in a few months it became a primary ('top tier') journal in the life sciences and biomedicine.

In chemistry research publishing a key role is played by two of the world's oldest scientific societies (the RSC and the American Chemical Society) whose highly reputable journals host in their early issues (going back to more than a century ago) some of the key advances in the chemical sciences. These journals and then all major journals in chemistry, we forecast in conclusion, will likely adopt this new model of scientific publishing, eventually allowing research chemists to get rid of the reliance on journal 'brand' and its main feature, the journal impact factor.

Notes

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