

Open access publishing in chemistry: a practical perspective informing new education

In the late 1990s chemists were among the early adopters of open access (OA) publishing. As also happened with preprints, the early successful adoption of OA publishing by chemists subsequently slowed down. In 2016 chemistry was found to be the discipline with the lowest proportion of OA articles in articles published between 2009 and 2015. To benefit from open science in terms of enhanced citations, collaboration, job and funding opportunities, chemistry scholars need updated information (and education) of practical relevance about open science. Suggesting avenues for quick uptake of OA publishing from chemists in both developed and developing countries, this article offers a critical perspective on academic publishing in the chemical sciences that will be useful to inform that education.

Keywords

open access; open science; education; open access in chemistry; preprints; open chemistry



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Introduction

In the late 1990s, chemistry scholars were among the first adopters of open access (OA) publishing in the early digital era, namely of publishing scientific articles in journals freely accessible on the internet. Writing in 2007 in one such new OA journal, Todd reported that in chemistry there were 'over 50 open access journals'.¹ Examples include *Arkivoc* publishing OA papers on synthetic organic chemistry since 2000 and the *Beilstein Journal of Organic Chemistry* launched in 2005. Neither journal requires authors to pay an article processing charge (APC).

Publishing scientific articles accessible without restrictions greatly improves the visibility of the freely available study. Accordingly, in a 2004 study comparing the number of citations of articles in physics published between 1992 and 2002 and subsequently made OA by self-archiving with the citations of articles from the same journals that were not made OA by their authors, Harnad and Brody first unveiled that the OA/non-OA citation ratio varied between 2.5 and 5.7.²

'chemistry scholars were among the first adopters of open access publishing'

2 As also happened with preprints,³ the early successful adoption of OA publishing amongst chemistry scholars subsequently faded away. As a result of investigating 100,000 research articles published between 2009 and 2015 in the basic sciences in 2016, chemistry was found to be the discipline with the lowest proportion of OA articles (fewer than 20% of articles were openly accessible on the internet).⁴ For comparison, more than 50% of biomedical research and mathematics papers were freely available.

The advantages in terms of enhanced visibility, number of citations, career and funding opportunities of open science, however, are too numerous for chemistry scholars to continue to ignore it. By 2018, the percentage of chemistry papers published as open access (in the Web of Science category 'chemistry multidisciplinary') had increased to 26% of the total.⁵

Evidencing the enhanced impact of OA journals, in 2017 the top three most cited multidisciplinary scientific journals were all fully OA (Table 1).

Rank	Journal	Number of citations
1	<i>PLOS One</i>	138,828
2	<i>Scientific Reports</i>	128,437
3	<i>Nature Communications</i>	83,086
4	<i>Nature</i>	73,840
5	<i>Science</i>	67,088

Table 1. Top five multidisciplinary scientific journals ranked by number of citations in 2017. [Source: Clarivate Analytics, 2018]

As remarked by Markram,⁶ the number of citations of *PLOS One*, an open access journal, in 2017 (138,828) was only slightly lower than the number of citations of *Science* and *Nature*, both subscription journals, combined (140,928). Similarly, the number of citations of the top three OA journals (350,351) in the same year was more than twice that of the two subscription journals combined.

Under these circumstances, continuing to rely on the 'old' publication model by which manuscripts are sent for peer review and waiting on average nine months before publication,⁷ is no longer tenable in chemistry. Most research chemists have never received education about open science or on how to shift from conventional publishing in paywalled journals to OA publishing. Hence, what chemistry scholars currently need is updated education on open science in the digital age, which is of practical relevance to their work.⁸ To illustrate the limited educational activities available on the topic, it is enough to conduct a Boolean search on Google Scholar using the queries 'open access' and 'chemistry' or 'open science' and 'chemistry' to find that few studies have been devoted to the role of open science in chemistry. One study emphasized the importance of open science as a research accelerator.⁹ Another focused on open science for identifying chemical compounds in the environment that are not yet captured in chemical databases,¹⁰ while one on chemistry 'crowdsourcing' (the solution of problems through a distributed network of people) and open notebook chemical research made the laboratory notebook public on the internet almost in real time.¹¹ The first study on preprints in chemistry was published in 2017 in OA format¹² followed by an update in 2020 reporting the slow rise of preprints in the chemical sciences.¹³

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Suggesting avenues for quick and effective uptake of OA publishing by research chemists in both developed and developing countries, this article offers an updated critical perspective on academic publishing in the chemical sciences that will be useful to inform the previously mentioned new education.

Current state of open access publishing in chemistry

By early November 2020, the Directory of Open Access Journals (DOAJ) listed 144 OA journals for the subject 'chemistry', 72 of which did not levy any APCs.¹⁴ Table 2 lists selected titles and the journals' fields of study.

Field	Journal
Organic chemistry	<i>Arkivoc</i>
Organic chemistry	<i>Beilstein Journal of Organic Chemistry</i>
Materials chemistry	<i>Beilstein Journal of Nanotechnology</i>
All fields	<i>Chemical Science</i>
All fields	<i>ACS Central Science</i>
Lipid science	<i>Grasas y Aceites</i>
All fields	<i>CHIMIA</i>
History of chemistry	<i>Substantia</i>
Materials chemistry	<i>Nanochemistry Research</i>
Surfaces and interfacial phenomena	<i>Journal of Applied Surfaces and Interfaces</i>

Table 2. Ten selected OA chemistry journals not levying an APC

An increasing number of national chemistry societies publish OA journals devoid of publishing costs for authors and their employers. The Swiss Chemical Society, for example, publishes *CHIMIA* both online and in print. Listed (indexed) in the most important databases for chemistry research, the journal is published ten times a year and in 2019 had a journal impact factor (JIF) of 1.478.

Similarly, the Iranian Chemical Society publishes *Nanochemistry Research*. In 2015, the publishing division of the American Chemical Society (ACS) launched *ACS Central Science* which, like *Chemical Science* published by the Royal Society of Chemistry, does not levy any APCs. For comparison, in 2019 *Chemical Science* published 1,306 articles, while in the same year *ACS Central Science* published 247 studies.

Public research bodies also publish OA chemistry journals such as *Grasas y Aceites*, published by Spain's Research Council's (CSIC) Instituto de la Grasa. Published on the CSIC website in a yearly volume divided into four quarterly issues appearing in March, June, September and December, the journal (JIF 1.440 in 2019) is a key literature reference for all scholars working in the field of lipid science and technology. Similarly, since 2017, the University of Florence has published the journal *Substantia* on the website of Firenze University Press. Though focusing on the history of chemistry, the journal also publishes special issues with studies from eminent scholars that range from 'Open Science'¹⁵ to 'Water in biology: what's so special about it?'.¹⁶

Large chemistry publishers publish several OA chemistry journals (Table 3), generally adopting the APC as a source of revenue.

Field	Journal
All fields	<i>ChemistryOpen</i>
All fields	<i>JACS Au</i>
All fields	<i>RSC Advances</i>
All fields	<i>ACS Omega</i>
All fields	<i>BMC Chemistry</i>
Polymer science	<i>Polymers</i>
All fields	<i>Open Chemistry</i>
Catalysis science	<i>Catalysis, Structure & Reactivity</i>
Green chemistry	<i>Current Research in Green and Sustainable Chemistry</i>
Organic chemistry	<i>PeerJ Organic Chemistry</i>

Table 3. Ten selected OA chemistry journals levying an APC

BioMed Central Group, an OA publisher founded in Great Britain in 2000, was acquired by Springer in 2008. At the time of the acquisition, the publisher produced 180 journals including seven chemistry journals.¹⁷ Wiley started to publish *ChemistryOpen* in 2012 in partnership with the ChemPubSoc Europe, a consortium of 16 European chemical societies. The Royal Society of Chemistry converted *Chemical Science* to be an OA journal in 2015 and waived the APC. The following year, the same publisher converted *RSC Advances*

4 (the world's largest chemistry subscription journal with 13,287 articles published in 2016) to open access, setting the APC at £500 for all authors for the first two years (2017 and 2018), and subsequently at £750. Due to the introduction of the APC, the publisher expected the journal to publish 'in the region of 7,000 articles in 2017',¹⁸ remaining the largest chemical science journal. Indeed, in 2017 the journal published 6,675 articles, followed by 4,767 papers in 2018 and 4,801 in 2019.¹⁹

Chemistry scholars willing to publish their studies as open access can also opt for publication in multidisciplinary OA journals, many of which are owned by well-established publishers. Examples include *Scientific Reports* and *Nature Communications* (Springer Nature), *Science Advances* (American Association for the Advancement of Science), *Advanced Science* (Wiley) and *Heliyon* (Elsevier). Owned by a non-profit publisher, *PLOS One* is another cross-disciplinary OA journal publishing chemistry studies.

Journal	Article processing charge
<i>ChemistryOpen</i>	EUR 1,800
<i>JACS Au</i>	USD 5,000*
<i>RSC Advances</i>	GBP 750
<i>ACS Omega</i>	USD 1,250
<i>BMC Chemistry</i>	GBP 1,570
<i>Polymers</i>	CHF 1,800
<i>Open Chemistry</i>	EUR 1,200
<i>Current Research in Green and Sustainable Chemistry</i>	USD 2,250
<i>PLOS One</i>	USD 1,695
<i>Science Advances</i>	USD 4,500
<i>Advanced Science</i>	USD 5,000
<i>Nature Communications</i>	GBP 3,790
<i>Heliyon</i>	USD 1,750

Table 4. APC values in different currencies for selected chemistry and multidisciplinary journals as of late 2020
*Selecting CC-BY license, USD 4,000 when selecting CC-BY-NC-ND license

Finally, most publishers of chemistry journals allow individual articles to become open access upon payment of an APC. The resulting journals allowing this option are called 'hybrid' journals, to distinguish them from fully open access journals. 'Gold' and 'platinum' open access journals indicate, respectively, journals for which the publisher levies or does not levy an APC. Originally, the colour codes to classify journals included 'gold', providing immediate OA to research articles, and 'green', allowing authors to deposit their peer-reviewed manuscripts in OA repositories after an embargo period.²⁰

In chemistry too, there are significant differences in APCs across a range of OA journals (Table 4). As was recently shown by economics scholars, this large variance is not explained by the cost of production but by other drivers, collectively identified by the scholars as 'market power'.²¹

In detail, the average APC can be modelled as a constant term of \$768.1, interpreted as the production cost of processing an article for an OA journal, plus the $JIF \times 132.5$ (a one-unit increase of the JIF increases the APC by \$132.5), plus the compound effect of being a big publisher amounting to $\$447.6 + \$1.13 \times \text{pub. age} + \text{big. pub.}$, namely the product of publisher age and size because age only counts in combination with being a big publisher (otherwise age increases average APC by only \$1.13).

The structure of the chemistry publishing industry

In 2017, trying to answer the question why scholars continued 'to give their labour – as authors, referees and editors – to publishing firms that do not, in fact, circulate knowledge widely and affordably',²² a team of scholars in open science suggested that:

- 5 'The answer lies in a lack of detailed understanding among academics of the historical and economic forces at play in academic publishing; and in the success with which big publishers have learned how to make themselves apparently indispensable to the academic prestige economy.'

Rank	Publisher	Average citation
1	American Chemical Society	6.88
2	Royal Society of Chemistry	5.13
3	American Physical Society	4.29
4	Oxford University Press	3.82
5	Frontiers	3.63
6	Elsevier	3.59
7	MDPI	3.3
8	PLOS	3.3
9	Wiley	3.27
10	IEEE	2.75
11	Springer Nature	2.63
12	Institute of Physics	2.1
13	SAGE	2
14	Wolters Kluwer	1.97
15	Hindawi	1.94
16	American Institute of Physics	1.7
17	Taylor & Francis	1.59
18	Cambridge University Press	1.54
19	Walter de Gruyter	1.16
20	Science Press	1.01

'the success with which big publishers have learned how to make themselves apparently indispensable to the academic prestige economy'

Table 5. Top 20 publishers by volume, ranked by number of average citations received by articles published in 2016, 2017 and 2018. [Source: SCImago, 2019]

Data in Table 5 show the average citations per article over a three-year window (2017–2019) for the 20 largest publishers by volume (total documents in 2019).²³ The American Chemical Society and the Royal Society of Chemistry, each publishing tens of subscription journals, lead the ranking. Furthermore, referring to articles published by those societies over the previous three-year window (2015–2017), the average number of citations per paper was substantially higher for subscription journals when compared to OA journals.

These two facts alone help to explain why in 2018 some 74% of chemistry articles were still published in subscription journals. Chemistry is the most concentrated segment of the scientific publishing industry with, in 2013, only five publishers publishing more than 70% of chemistry studies.²⁴ With 207 journals from 20 publishers, chemistry was recently found to be the third (after multidisciplinary and space science) scientific discipline in terms of market concentration, measured by the Herfindahl-Hirschman index.

Another highly reputed learned society, the American Physical Society, ranks third among the largest 20 publishers, classified by number of average citations received by articles published in 2016, 2017 and 2018 (Table 5). In this case, however, the number of citations of articles published in OA journals is almost twice as high as that in non-OA journals. The reason is due to the fact that physicists are familiar with OA papers thanks both to preprints posted in arXiv since the early 1990s and widespread use of 'green' self-archiving.

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Openly accessible, impactful science

'If you include journal impact factors in the list of publications in your curriculum', wrote Curry citing Seglen's 1992 work²⁵ showing the highly skewed pattern of citation distribution

6 for which only a few papers in a journal account for most of the journal's total citations, 'you are statistically illiterate'.²⁶

Given the fact that universities and research bodies continue to use the JIF and other citation-based metrics such as the h-index²⁷ to evaluate researchers and for granting research funds, it is not surprising that researchers continue to strive to publish in high JIF journals.

For example, over a few months some 34,000 biologists signed the online petition initiative by Varmus, Brown and Eisen calling for all scientists, by late 2000, to 'pledge that, beginning in September 2001, we will publish in, edit or review for, and personally subscribe to only those scholarly and scientific journals that have agreed to grant unrestricted free distribution rights to any and all original research reports that they have published, through PubMed Central and similar online public resources, within 6 months of their initial publication date'.²⁸ Actually, most signatories continued to publish their work in paywalled journals (and to review journal manuscripts for free, as well).

Yet, as noted by Harnad in 2005,²⁹ over 90% of journals gave authors the permission to self-archive their papers on personal websites or in institutional repositories. Underlining the inconsistency, Harnad continued:

'Now SUPPOSE that — in addition to performing the keystrokes required to sign the 2001 *PLOS* open letter (pledging to boycott journals unless they become OA journals), each of the 34,000 *PLOS* signatories had *also* performed (or deputized a librarian, secretary or student to perform for them) the few further keystrokes it would have required to make *just one* of their own year-2001 articles OA by *self-archiving* it, free for all, on the web.

'THEN the number of OA articles (34,000) resulting from just that minimal act would already have doubled (to 60%) the percentage of OA articles (34%) among the approximately 55,000 Biology articles indexed by ISI in 2001; it would also have exceeded the total number of articles published by both BioMed Central and *PLOS* journals from 2001 to the present (c. 20,000).'

The very same inconsistency was noted in 2014 for scholars of all disciplines upon analyzing 1,066,079 articles published between 1999 and 2011 (social sciences 91,729 articles, life sciences 202,833, health sciences 282,096, and physical sciences 489,421), 80.4% of which could be self-archived after one year of publication either on personal websites or in institutional repositories, whereas only around 12% of total annual articles are actually self-archived.³⁰ 'The results', wrote Laakso concluding the study, 'highlight the substantial unused potential for green OA'.

'today's scholars are, in large part, unaware of the possibilities offered by today's scholarly communication'

This fact provides evidence that today's scholars are, in large part, unaware of the possibilities offered by today's scholarly communication, and further substantiates my viewpoint that the full transition to open science requires new education for today's doctoral students and early career researchers, on scholarly communication in the digital era.

Outlook and conclusions

OA academic publishing is thriving. With over 106,000 articles published in one year, MDPI, an OA multidisciplinary publisher jointly established by a former research chemist in 1996, in 2019 became the world's fifth largest academic publisher.³¹ The APCs charged by the publisher for its journals, many of which are devoted to chemistry, nanotechnology and materials science, are in the order of CHF1,600–1,800.

Most publishers of 'gold' OA journals offer discounts on the APCs, for example to scholars submitting from developing countries, and even waive them in certain cases. However, given the APC levels shown in Table 4, it may not be surprising to learn that even in the U.S., a

7 wealthy nation leading global scientific production for over a century, OA publishing in journals levying an APC is used by a disproportionately larger proportion of professors at elite institutions,³² namely at research centres receiving huge grants.

With the early success of the Chemistry Preprint Server (CPS), publishing some 500 studies from scholars based in 51 countries two years after its launch in August 2000,³³ research chemists were the first after physicists, mathematicians and computer scientists to show real interest in preprints and in open science. Today, the fact that chemistry scholars understand and value open science is shown, for example, by PubChem, an online repository for information on chemical substances and their biological activities, that 11 years after its inception in 2004 already hosted more than 157 million chemical substance descriptions.³⁴

Put simply, most research chemists have not been trained on scholarly communication in the digital age and open science. The result is that in the early 2020s, the vast majority of chemists still do not self-archive research papers, thereby losing the opportunities for enhanced use and citation of their own work. Whether new chemical methods, materials, ideas or models, the main objective of any chemistry scholar is to see her/his research findings used by the global chemistry community. This, unique among all scientific disciplines, includes researchers working for a huge global industry comprising chemical (and pharmaceutical) companies, which is central to the wealth of any country.³⁵

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Like other scholars in the basic sciences, chemistry researchers are also interested in citations which play a central role in review, promotion and tenure procedures used by their employers.³⁶ By quickly fulfilling the 'unused potential for green OA', chemistry scholars should make their articles openly accessible through self-archiving on institutional or personal websites and publish their papers in preprint form. Beyond recording a rapid increase in the number of citations, those scholars will enjoy the benefits of open science in terms of enhanced collaboration, job and funding opportunities,³⁷ as well as enhanced citations and online attention.³⁸

In other words, rather than paying the APCs of 'gold' OA journals, chemistry scholars should take advantage of the new tools provided by the internet and by progress in scholarly communication, and freely publish their own work first as preprint and then in any journal not levying an APC, namely 'platinum' OA journals, or even in paywalled journals. After the embargo period (often 12 months, but for certain journals 24 months), the article will be made openly accessible on the internet by self-archiving it.

'rather than paying the APCs of 'gold' OA journals, chemistry scholars should ... freely publish their own work first as preprint and then in any journal not levying an APC'

In promotion and tenure processes, chemistry scholars are chiefly evaluated based on research, with evaluation often failing to reward teaching and service, thereby devaluing faculty work in those areas.³⁹ By making their work openly accessible, the same scholars will drive improvement in all of the citation-based metrics which are still narrowly used to evaluate them, freeing time for teaching, sharing of knowledge with the public, writing books and grant proposals and preparing teaching materials to foster student creativity in the digital age.⁴⁰

Inexorably, then, thanks to widespread uptake of OA publishing, research chemists will start to value the benefits of open scholarship including the sharing of educational resources,⁴¹ thereby dramatically improving outcomes in all three main fields of academic activity: research, education and service to society.

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Abbreviations and Acronyms

A list of the abbreviations and acronyms used in this and other *Insights* articles can be accessed here – click on the URL below and then select the 'full list of industry A&As' link: <http://www.uksg.org/publications#aa>.

Competing interests

The author has declared no competing interests.

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