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# On the Future of Scientific Publication

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**Abstract**

*We give a brief review of the rapidly changing landscape for scientific publication, especially in regard to scientific archival journal publication. Some of the many challenges and opportunities are outlined. These include the various forms of open access publication, the associated links to archived open data, and ways for addressing the future needs of authors, reviewers, the participating science communities in general, and overall sustainable scientific publishing endeavours. A picture is presented of the future scope of scientific publishing, and the possible roles of scientific professional societies in facilitating the achievement of well-curated global open science.*

## 1. Introduction

Scientific publishing is currently undergoing unprecedented changes, but has been, and will remain, fundamental to the recording, dissemination and utilization of scientific results and ideas. Most scientific work has traditionally been published in journal articles, books or theses. Here we concentrate on journal article publication as we consider that it represents the core of the scholarly communication process: how journal publication develops over the coming decades will be crucial in determining the future of scientific publishing.

It is over 350 years since the first academic journals, *Journal des sçavans* and *Philosophical Transactions of the Royal Society*, started publication in 1665. Subsequently, the creation of professional scientific societies and publication of their journals dramatically accelerated the diffusion of new ideas that were to be crucial for the development of modern society. Over a thousand journals were founded in the 18th century and the number has continued to grow rapidly ever since (Kronick, 1976; Tenopir & King, 2014). At the start of the 20th century, most journals continued to be run by scientific societies, who had direct access to expert referees and editors in their field, and also had a ready-made readership within their membership. However, by the middle of the century, commercial publishers began to have a significant presence in the journals market and scientific society journals started to be acquired or co-published by commercial publishers. This trend has continued to the present day with the role of many scientific societies in scientific publishing steadily diminishing.

The commercialization of scientific publishing has been accompanied in the last 30 years by development of the first digital journals and a subsequent move away from print to online distribution. Concurrent with this, as is discussed below, a movement towards open access in publishing, and open science in general, has been developing. Both these trends, and the opportunities they provide, will have a profound effect on the future of scientific publishing.

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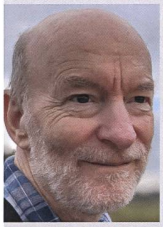

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Sustainable models need to be found that will allow publications to be available to all contributors and readers globally, as well as making full use of the digital environment by integrating articles and their data. The continued involvement of professional scientific societies will be important in ensuring that contributions continue to be moderated, evidence-based, reviewed and curated.

**2. The open access advantage**

For well over a century, the traditional model for scientific research publishing (and much of scholarly publishing in general) has comprised the submission of an article to an editor, a review process involving the appraisal of the article by independent reviewers, revision of the article and further review as needed, and finally (hopeful) acceptance of the revised article for publication – provided at least any major issues identified in the review process have been addressed. While this whole process has traditionally been free of charge for the author, only the title, author list and affiliations, abstract, keywords, citation information, and perhaps the list of literature cited, have been freely available to the reader. The main contents of the article, itself, have been behind a paywall, and it is the reader, or reader's institution, who has supported the review, reproduction and publication costs through a subscription payment, either for the specific article or for the publishing journal. In recent years, this situation has been changing dramatically for three main reasons (UNESCO, 2021). Firstly, there is an increasing global sense, especially in the developing world, that science and the fruits of scientific research should be available to all, and not reserved to a privileged group of participating researchers and institutions that are able to pay for access to the results of scientific research. This has the effect of excluding many developing countries, and smaller or poorer entities everywhere, from the benefits of scientific research. Secondly, there is an increasingly strong demand, especially in the more developed economies, for publicly funded research to be freely available in the public domain. Thirdly, as discussed further below, there is an increasing need to connect scientific publications to the data on which they are based (Trewhella *et al.*, 2017; Helliwell *et al.*, 2019). In part, this is because much of the value of scientific research lies in the data it produces, as much as in any publication describing the work. However, for the fruits of scientific research to be useful, it is also essential for independent researchers to be able to reproduce the results supporting the assertions made in research publications. Thus, the concept of open data is integral to open science, and open access publication of the associated research is becoming essential both to guide the independent researcher through the data and metadata that are made available (open) and to establish a statement of record regarding the research performed that produced the data.

Various forms of open access (OA) publication have emerged in recent years, each with their advantages and disadvantages (Gatti, 2020; International Science Council, 2021). In all cases, it is essential of course for the integrity of the scientific record that any financial aspects of the OA process are kept entirely independent from the peer review of scientific content that determines the need for revision and ultimately whether a submitted article is accepted or rejected for publication. A very brief summary of some major forms of open access follows:

Gold OA refers to the actual version of record of the published journal paper being made freely available without limitation on payment of an article processing charge (APC) by the authors or one of their institutions to the journal publishers. An obvious advantage is that the authentic research statement of record is freely disseminated; a disadvantage is that, unless a "read and publish" deal is in place with one of the authors' institutions, research funds must be allocated to the APC payment (rather than further research) and APCs are frequently higher than can be subsumed into incidental expenses. Green OA, in contrast, refers to the final accepted version of the (revised) manuscript being submitted to an open publication database. While some institutional costs are inevitably be involved, there is no APC required of the authors and the database version of the paper is generally findable in searches of the actual journal publication. However, the published journal paper remains behind the journal's subscription pay-wall. Other disadvantages are that the author must participate in a second independent proof-check, and the green OA article may not be the formal version of record. Another major form of emerging OA is the uploading of paper drafts to open preprint servers, where papers can be commented upon, discussed, and the work essentially reviewed in the open domain. This can present major OA advantages in terms of advancing a given research field, but there is still a need to produce a version of record with a specific citation for final publication. Other forms of OA exist such as journals that essentially invite authors to crowdfund OA for all papers published in a given year.

An implicit assumption for scientific research journals that are not gold OA is that they will continue to function in something like their present form based at least partly on a subscription income model. However, the general call for open science, as well as specific research funding initiatives, such as *Plan S* (cOAlition S, 2020),

make it increasingly unlikely that a research journal subscription-funding model is sustainable in the long term. Increasingly, science research publication will need to transition to a fully gold OA operation, with APCs set at a sufficient level to avoid running deficits while at the same time allowing for significant APC discounts and waivers for researchers in developing parts of the world whose institutions are unable to pay the APC. Not to do so will exclude those unable to pay from the research communities of the future, frustrating a principal pillar on which the precepts of open science are based.

While it is too early to predict the scientific journal landscape that will ultimately emerge from these pressures, one major advantage for authors of OA papers is becoming clearer: a significant increase in the citation rate of published OA papers, compared to their subscription-based counterparts. Of the International Union of Crystallography (IUCr) journals, the *Journal of Synchrotron Radiation* (*JSR*) is planned to be fully (gold) OA from January 2022. In a recent Editorial (Kvashnina *et al.*, 2021), the editors compared the average number of citations for gold OA papers published in *JSR* since 2018 with that of non-OA papers published over the same period. OA papers have an average of 6.0 citations each, compared to only 3.7 citations each on average for non-OA papers. This is despite the fact that the non-OA papers excluded only gold OA papers while green OA papers were included in addition to subscription-only papers. Other studies suggest that green OA can be as effective as gold OA in increasing journal citations (Young & Brandes, 2020), but this depends on what papers are being compared in each category. Overall, it does seem that the increased citation rate of OA papers (gold plus green) over non-OA papers could be more than 30% across many scientific research fields. This citation advantage of OA is significant not only for individual authors, but also for institutions, and even countries, where the number of citations per research article is frequently considered a quality measure of the health of scientific research output.

### 3. Open access and open data

It has always been important that the experimental data underlying scientific claims in a journal article are made available to readers. Until recently, this could often be achieved by including the data in the article itself. However, in the digital age, datasets have become larger and more complex, and the number of cases where the data are not available with a journal article has been increasing. The future journal article will therefore need to be extensively interlinked to relevant datasets, and ideally machine readable.

As part of developing open science, strategies are required to ensure that the relevant data are available for peer review and publication. Open data requirements have been set out in the FAIR data principles (Wilkinson *et al.*, 2016). According to these principles, data and metadata need to be (*a*) findable by humans and computers, (*b*) accessible, (*c*) interoperable with applications or workflows and (*d*) reusable (this requires the metadata and data to be well described).

In crystallography, the IUCr have been working for many years to ensure that the correct data and metadata are openly available. As long ago as the 1960s, Kennard *et al.* (1967) prescribed a set of items that should be reported in a single-crystal structure determination. This led to the call for a standard data-interchange format that was developed as the crystallographic information file (CIF) and associated dictionaries (Hall *et al.*, 1991). This format was adopted by IUCr Journals in 1991, and mandatory electronic submission of data was introduced as part of journal article submission in 1995. This was possible because developers of software used for crystallography were persuaded to enable the output of CIFs. The IUCr also worked with other publishers of crystallographic journal articles to encourage them to adopt CIF. In subsequent years, the checkCIF data validation service was set up for use by journal referees and also as a public service. These measures have allowed the IUCr to validate the crystal structures it publishes, and define the roles of authors and referees in checking structures. In addition, the data could be linked to (and published with) the journal article. The availability (reusability) of the data has enabled many features such as interactive 3D views of published structures (Strickland & McMahon, 2008). In more recent years, the IUCr and other organisations such as the Protein Data Bank have also worked on data-interchange dictionaries for other types of data related to crystallographic research. Where such data are available, they are again linked to the published journal article.

A more general approach has been taken by, for example, the *Nature* journal *Scientific Data* [see Box 6 in International Science Council (2021)]. Authors deposit their data in a recommended data repository as part of the manuscript submission process. The datasets must be made available to editors and referees at the time of submission, and must be shared with the scientific community as a condition of publication. The journal requests that the deposition is to a discipline-specific, community-recognized repository where possible.

When open access is combined with open data, the prospect of a machine-readable article becomes

attractive. Potential benefits of a move towards a more data-centric scientific literature include: (*a*) an increase the discoverability and interpretability by computers of the data that the papers are based on, and (*b*) ensuring provenance information and correct attribution of the data to the content creator.

The expertise to define the metadata necessary to make an open data component machine-readable lies within the relevant professional scientific societies. Ideally, metadata is captured during experimental work, and throughout the research and publication chain. In this way a linked digital infrastructure (with links back to the experiment, funding, preprint etc., and forward to subsequent publications) can be created. The IUCr is actively looking at a number of use cases for machine-readable articles, and expect this to be a feature of future scientific publications.

A number of future initiatives could be envisaged for making the texts of journal articles more machine-readable, e.g. for text mining. Publishers could help such initiatives by making articles available in an industry standard xml format such as JATS (Journal Article Tag Suite, NISO Z39.96), as well as providing articles as html and pdf files. The various representations of the article as well as associated data and metadata could then be available via a REST-API. making a fully machine-readable article.

In summary, open access and open data will provide new routes for finding and assessing scientific articles. It will be important to try to ensure that all components of such articles, including the text and data, are machine and human readable.

## 4. The role of professional societies in open access science publication

A major challenge of widely available open access to scientific research results is to develop robust capabilities for discerning results and publications that advance and enhance the scientific research record from those that do not. In this connection, professional scientific societies have a critical role to play in the ongoing transition to a world of open science. Not only do these societies identify with the professional research standards and practices associated with their given research field, but they also include a strong educational and teaching role within their remit, focused on bringing new researchers into the field. Thus, the research journals of professional scientific societies have a major responsibility to provide quality research review systems for submitted articles – separating the review process from any financial inducements associated with open access, doing everything possible to protect the integrity of the scientific record. This must be done in a rapidly changing business model for scientific journal publication, as detailed in previous sections: research funders are imposing requirements that work be published in fully OA journals, while large commercial publishers increasingly control the OA business model with large-scale arrangements that bundle multiple journals and access modes (Gatti, 2020; International Science Council, 2021).

Most professional society scientific research journals rely on the dedication of their own research community to serve as volunteer journal editors and reviewers. Collectively, they can guide new researchers in the field not only regarding technical and scientific expertise but also in good publishing practices and data curation. They can help editors address difficulties in obtaining thorough paper reviews and support referees with useful information and software for data validation, *etc.* Indeed, the professional society journals for a given scientific discipline are in the best position to take a lead in defining the data deposition requirements (Trewhella *et al.*, 2017; Helliwell *et al.*, 2019) for legitimate re-use of open data, rather than re-use for predatory journal practices (such as excessive multiple publications based on the same data). They also have access to expert knowledge in their research community to develop data-exchange standards and specialist tools for authoring and visualizing data. Through sensible data requirements and data peer review, set out by the scientific community they serve, professional society research journals are frequently in the best position to recognize and address fraudulent data or paper submissions.

In essence, professional society research journals are generally associated with a scientific research community that is open-minded to evidence-based contributions and new ideas, but not to unsupported assertions or unfounded speculation. However, to operate successfully in a fully OA environment, they will need to be able to set APCs at a level that both sustains the journal operation, itself, and provides a stream of funding to support the society's teaching and education, outreach and knowledge curation, for which the society was originally formed.

## 5. Conclusions

In summary, there are many competing and conflicting pressures associated with the future of scientific publication. Indeed, the prospects for viable business models for open access scientific publication present many challenges and can become rather complex. It will remain essential to ensure that the tensions of future OA scientific publication remain creative, and do not become disruptive and remain creative in establishing a well-curated scientific record. However, as we have outlined in this article, potentially

exciting new opportunities are gradually emerging for scientific publication. These include electronic linking of scientific papers to the data upon which they are based, openly accessible to other researchers, and tractable to machine-readable cross-linking between researchers in similar or even very different fields. In this connection, artificial intelligence will no doubt have an important part to play in improving future scientific publication and dissemination. On balance, there are many grounds for optimism that, ultimately, science and effective open science publication can provide a powerful but non-threatening global unifying force. ■

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