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Preprints Are Here to Stay: Is That Good for Science?

82

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Contents

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Abstract

Scholarly communication, largely encased in traditional publications such as journals, books, and conference papers/presentations, proved ineffective during the COVID-19 pandemic. The need for change has encouraged redefining editorial policies, sharing research data in open access, accelerating and improving the peer review process, and the emergence of new ways of communicating through preprints. Although common in some research fields for decades, the increased use of preprints, in other disciplines, like medicine and health, has shown its vital role in rapidly exchanging information while opening up many questions and concerns at the same time. The benefits of preprints must be therefore balanced with the challenges they bring, especially concerning the validity and integrity of the published research and translation of preprint policies into practice. This chapter will provide a comprehensive review of preprint policies and practices. Two experts in journal research and peer review, one from medical and the other from social science research fields, join their expertise to discuss the future of preprints, particularly how different publishing stakeholders can help make research results available as soon as possible to those who need them.

Keywords

Preprint · Archive · Peer review · Publishing · Journals · Editorial policies · Indexing · Open access · Open science

Introduction

The National Library of Medicine defines preprints as "complete and public drafts of scientific documents, not yet certified by peer review" (National Library of Medicine, 2023). (Depending on the discipline, "preprints" are called also "e-prints," "working papers," or "manuscripts." In this chapter, we use the term "preprint" as it is widely accepted by the global research community.) However, some authors of preprints do not intend to publish them in a peer-reviewed publication (Tennant et al., 2018). Additionally, a preprint can be large datasets with descriptions, protocols, (parts of) a thesis, presentations, reports of negative results, commentaries, videos, and more (Bourne et al., 2017; Desjardins-Proulx et al., 2013), which do not pass a standard peer review process. A preprint can also be peer-reviewed by a community (ReimagineReview, 2022), by a combination of artificial intelligence with human expert peer review (Early Evidence Base, 2022), or by reviewers exclusively (Sciety, 2022). Ambiguities and disagreements around the definition of preprints need to be addressed to offer more precise and less anachronistic terms in such an innovative area (Chiarelli et al., 2019a). The main purpose of preprints is to disseminate research results to the scientific community, establish ownership of results, and receive feedback from the professional community before submission to a journal. The COVID-19 pandemic unleashed the growth of preprints by creating

the need for a fast exchange of information to make clinical decisions in circumstances of rapidly spreading disease and high hospitalization and mortality rates which burdened the health systems around the globe (Nabavi Nouri et al. 2021).

Preprints, "not filtered by their perceived quality or pertinence" (Desjardins-Proulx et al., 2013), can reduce the competitive pressure imposed on researchers and reduce the negative consequences of filtering scholarly information (Guédon, 2014). Being a response to the failures of traditional publishing, preprints can solve some present issues with the replication crisis, peer review, and research assessment systems. Although the growth of preprints brought essential benefits to the scholarly community, the public, and the policymakers, it raised several important ethics and integrity issues.

Preprint Servers

In some disciplines, preprints have been rooted in research culture long before 1991, when Paul Ginsparg established the first open preprint repository, arXiv (Wykle, 2014), primarily intended to serve the high-energy physics community. arXiv was first hosted by the Los Alamos National Laboratory (LANL) and then moved under Cornell University's stewardship in 2001. Today, arXiv is a free distribution service for more than 2 million scholarly articles in physics, mathematics, computer science, and others, with 4 million connections daily and 2.5 million downloads monthly, according to arXiv usage statistics.

During the 1990s, preprint servers were set up in different disciplines (e.g., life sciences, chemistry) and ceased due to differences in preprint cultures and the fact that many journals refused to publish submissions previously uploaded to preprint servers (Garisto, 2019). However, two of them are still active nowadays. The Social Science Research Network (SSRN) was created in 1994 and acquired by Elsevier in 2016, and Research Papers in Economics (RePEc) started in 1997, hosting preprints in economics.

The use of preprints in biomedical disciplines led to a significant increase in the number of preprint services in 2013 with the launch of bioRxiv and PeerJ Preprints, hosting several hundreds of preprints in the first few years (Puebla et al., 2022; Tennant et al., 2018). In addition, the Center for Open Science (COS) created the Open Science Framework (OSF) in 2016. This free and open-source project management repository supports researchers across their entire project lifecycle, providing rigor and transparency in research (Ravinetto et al., 2021) and offering OSF Preprints as one of its services. Hosted by the COS in the same year, engineering archive engrXiv, a preprint service for the psychological sciences PsyArXiv, and an open archive of the social sciences SocArXiv were created, the latest in response to the SSRN acquisition by Elsevier. Since 2016, the number of preprint servers, which differ in disciplines and geographical areas they cover, languages, technical sophistication, and penetration level, has grown significantly (Chiarelli et al., 2019b; Russell et al., 2021).

In August 2022, the Preprint Server Directory at ASAPbio (Accelerating Science and Publication in biology) listed 53 preprint services relevant to life sciences,
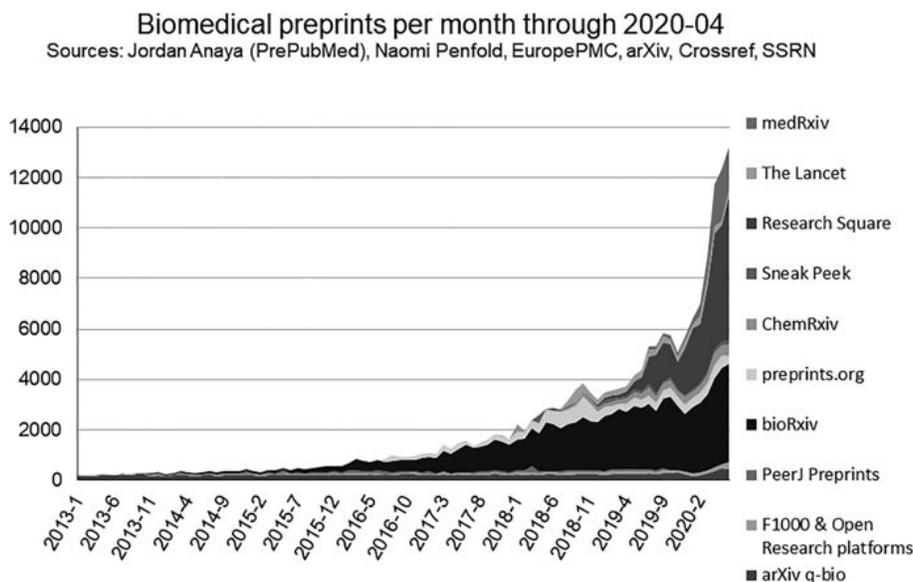
Fig. 1 Biomedical preprints per month, adapted from Polka and Penfold (2020). Reproduced under Creative Commons Attribution 4.0 International. The figure was modified from color to grayscale legend

biomedical, and clinical research with searchable information about their policies and practices, and its growth is regularly recorded (Fig. 1). Each preprint server is described with a rich set of metadata with added information on discipline, ownership type (e.g., academic community group, funding organization, publisher, academic institution, scientific society), and screening process (legal and ethical compliance, text overlap detection, misconduct or integrity check, data and code availability, authors, language, and scope).

Preprint aggregator Europe PubMed Central (Europe PMC) enables free access to more than 40 million publications from life sciences, including 500,000 preprints. To ensure harvesting only trusted sources, they developed a set of criteria for preprint servers (Europe PMC, 2022):

- *Peer review:* status must be identifiable on website displays and in machine-readable form.
- *Screening:* transparent screening procedure.
- *Metadata availability:* preprint metadata should include all the fields typical of a research article, including version information and links to peer-reviewed versions.
- *Access to metadata:* availability in a machine-readable format.
- *Access to full text:* without barriers.
- *Discipline-specific content:* easy identification and extraction of discipline-specific content.

- *License:* easy identification of the license type, preferably in a machine-readable format.
- *Publication ethics:* a public statement on policies on plagiarism, misconduct, and competing interests.

To maintain the academic rigor and credibility of the published content, preprint servers must have transparent and well-defined policies, submission requirements, and recommendations on reporting and research integrity.

Funders' Preprint Policies

Funders of scientific research are proactive promoters of the principles of open science, advocating faster dissemination of the results of the research activities they fund to increase its reach and impact. European funders gathered within the cOAlition S are, among other recommendations ensuring open access to all publications from research financed through cOAlition S members' grants, strongly encouraging early sharing of research results through preprints. Back in March 2017, the National Institutes of Health urged citing preprints in grant proposals and reports: "The NIH encourages investigators to use interim research products, such as preprints, to speed the dissemination and enhance the rigour of their work" (National Library of Medicine, 2017). The Wellcome also encourages other funders to exchange data, including preprints and datasets: "research findings are made available via preprint servers before journal publication, or via platforms making papers openly accessible before peer review, with clear statements regarding the availability of underlying data" (Wellcome, 2020). Besides boosting the use of preprints in grant applications and reports, some funders (e.g., Chan Zuckerberg Initiative and Wellcome) require posting preprints.

Publishers' Preprint Policies

Increasingly, publishers allow or even encourage preprint sharing in open preprint archives, and some even set up preprint servers (e.g., BMJ and medRxiv and American Chemical Society and ChemRxiv). According to Sherpa/RoMEO, in 2018, 48% of publishers allowed archiving of preprints, and the study of the preprint policies of 14 major publishers reveals that 78% supported preprints (da Silva & Dobránszki, 2019). In a more recent study of the top 100 clinical journals, 86% of these journals allow for submitting articles previously posted as preprints (Massey et al., 2020).

Discussing complex interactions between publishers and preprints, Smart (2022) defined several layers of the relationship: "uneasy relationship," acceptance, encouragement, participation, submerger, merger, and overlay. While some publishers allow submissions previously published as preprints, others actively encourage authors to make their submissions publicly available via preprint servers or even

post them on the preprint platform instead of the author (if the author agrees). A higher level of participation includes publishers who will post the preprint on a designated server automatically, after initial evaluation and screening, invite reviewers, and publish their reports together with the article. The last level of interaction is the so-called overlay journal, which can integrate software for managing the editorial process with a preprint server. This way, the manuscript submission takes place through the preprint publication and remains on the preprint server after the editors' evaluation and peer review. The overlay journal websites are used only for navigation and access to published articles hosted at the preprint server, bringing significant savings for the journal.

Some publishers are still not enthusiastic about integrating preprints into their publishing processes. According to Smart (2022), "unease relationships" are related to publishers not being eager to restructure their editorial workflows with unknown outcomes. Furthermore, employing preprints in editorial processes requires a new set of competencies and additional education for included stakeholders (researchers, editorial staff, publishers, funders, librarians, and repository managers).

Although publishers are changing their attitudes toward preprints, multiple levels of integration and experimentation mean that authors often do not know how to proceed and what is best for them and the discipline. The "Ingelfinger rule" of publishing embargo by journals is still deeply imprinted in traditional scientific publishing as a way of preventing duplicate publication, and authors are often unsure about the consequences of uploading a manuscript to a preprint server. This uncertainty is also increased by journals' unclear and insufficiently transparent policies related to the publication of preprints. It is therefore important to remove ambiguities in journals' preprint policies, including copyright retention (or transfer), selection of the open license of preprints (e.g., Creative Commons licenses), and possible engagement with media (Nature, 2022).

We can conclude that an increasing number of publishers realize that preprints are not secondary or competitive to traditional publishing but offer them new opportunities if integrated into submission systems and other editorial workflows. The community's pressure to shorten the time from submission to publication is often not aligned with complex and long-term editorial work. Therefore, it is helpful for publishers to investigate parallel processes offered by sharing the preprints, especially community feedback. Participating in quality maintenance of preprint servers and collecting immediate feedback from the scientific community can be helpful for journals in selecting high-quality preprints, as well as in the promotion of research integrity.

Benefits of Preprints

The pros and cons of preprint sharing have been discussed and analyzed in different studies (Chiarelli et al., 2019b; Desjardins-Proulx et al., 2013; Kavanagh & Kapitany, 2020; Puebla et al., 2022; Smart, 2022), and we here summarize the most relevant.

Free for Authors/Users and Supporting Open Science

After a decade of evolving open access to scientific information, primarily works published in journals and books, open science initiatives were launched to achieve transparency and openness of the entire research process and all types of research outputs. According to the European Commission, the strongest advocate of open science in Europe, "Open Science consists in the sharing of knowledge, data and tools as early as possible in the research and innovation process" (European Commission, 2021). Recently, the US White House Office of Science and Technology Policy updated the US policy guidance to make the publicly funded research results immediately available to the public (The White House, 2022). Preprints enable the open dissemination of research results without any barriers associated with journal subscriptions, paywalls, or fees. Compliance with the principles of open science is also visible through open licensing regulating reuse. Preprints encourage the sharing of research data and other types of research output.

Accelerating Scholarly Communication and Innovation

The availability of new knowledge can accelerate further discoveries. Preprints are published within a few days of posting on the preprint server, unlike traditional publications (books and journals), where the peer review and editorial process can last several months or years, during which the research results are unknown to the scientific community. Preprints allow researchers to communicate their research results with the community quickly and efficiently.

Priority Publication and Scoop Protection

Posting preprints on the preprint server gives authors priority over results and ideas, which is especially important in some highly competitive fields of research, where laboratories compete with each other for precedence. Preprint servers provide an acceptable way to establish intellectual property, making work publicly available immediately after the study is completed and not after the manuscript's acceptance by the journal. Also, prompt communication of findings enables quick feedback and encourages cooperation. Although there is a certain level of concern within the scientific community about the possible "scooping" of results, the long-term practices of disciplines with a preprint culture do not prove a higher level of unethical behavior (plagiarism, unauthorized altering, or falsification of results) than in traditional publishing. When Ginsparg was asked about arXiv experiences, he replied that scooping could not be a problem, given the community consensus that arXiv postings are accepted as date-stamped priority claims (Pewter, 2021). Preprints posted to trusted servers receive a digital object identifier (DOI) and are citable, searchable, and time-stamped, which counts for staking intellectual precedence. Additionally, many publishers, journals, and preprint servers are adopting scooping

protection policies (e.g., EMBO, *eLife*, and others). In fact, the culture of preprint encourages responsible research and fair practices in publishing.

Improving the Quality of Science Through Community Feedback

Preprint servers allow mostly informal commenting, and the provided feedback can help authors revise and improve the manuscript before either submitting it as a new version on the preprint server, sending it to a journal (Puebla et al., 2022), or publishing it as another type of publication. Although studies find a small percentage of preprints collecting comments on the preprint servers (Puebla et al., 2022), the possibility of ensuring dialogue with the author is still valuable. Perhaps the preprint commenting culture will become a common practice in the future. Also, preprint servers' comments are only a part of the possible provision of feedback, and social media and private channels should also be considered.

Democratization of Publication

The presence of bias, the Matthew effect of accumulated advantage, and various types of discrimination are not rare in traditional publishing. Preprint servers are not subject to such patterns and selectivity and offer a more democratic publication process. Additionally, preprint servers that follow the "green path" of open access (self-archiving) are a correction factor for the prevalent business models in scholarly publishing, often driven by profit. Regardless of business models and ownership of preprint servers, the democratization of publication and free access to scientific information represents a significant contribution to the development of science. Encouraged by these changes, even commercial publishers, such as Springer Nature, allowed all readers to access content that was otherwise only available to subscribers (SharedIt content-sharing initiative).

Author Publication Control

Where, when, and how to publish accurate research results are an author's entire decision, unlike publication in a journal where reviewers and editors make the final version of the article.

Documented History and Versions Available

It can be highly relevant in some areas to see the history of an article and how it has developed through different iterations. Publishing preprints ensures that all changes, additions, and informal comments are stored and accessible. This can be a valuable practice because it provides insight into the original views of the author.

Increased Visibility and Citation Advantage

Preprints are most often published under open-access licenses, which ensure not only unimpeded distribution but also reuse. Preprint servers usually enable a high level of interoperability so that published content is available through multiple sources. Therefore, preprints are associated with increased readership and citations and are more likely to be mentioned on social media (Wang et al., 2020). Furthermore, publishing preprints ensures more citation counts, not only of preprints but also of later published peer-reviewed work (Fraser et al., 2020; Fu & Hughey, 2019). Still, in the corpus of PLOS, with 7 journals and over 240 thousand articles, it seems that preprints are primarily cited in the Methods sections and that the preprint citation context significantly differs from that of journal articles (Bertin & Atanassova, 2022).

Boosting Early-Career Researchers

A publication delay can impede an impressive CV, reputation, employment, position, promotion, project funding, or scholarship for a researcher and thus negatively affect an institution or a funder. Therefore, publishing preprints, whose perceived value is high, can be very important, particularly for early-career researchers who are often pressured to show results in the shortest time. Public and immediate publication of research results, commenting, participation in reviews, posts on social networks, and citation of posted preprints can successfully contribute to the reputation of an early-career researcher, proving productivity, competencies, communication, and collaboration skills to their employers and funders (Sarabipour et al., 2019).

Leveraging Research Output

Preprints ensure the dissemination of results and ideas that are sometimes unsuitable for publication in journals that exclusively publish traditional journal articles. Examples of such publications include proposals, observations, and negative results. Such publications are important as they can, for example, better justify research investments. Enabling access to the early-stage research outputs preprints as a key method of rapid, author-driven publication of research findings offers a better return of investment for public funding.

Challenges to Preprints

The greatest challenge to preprints arises in research disciplines, like medicine and health sciences, where the published information can be used directly into practice or be incorporated into health practice guidelines before the findings have been peer-reviewed and verified.

Health information from preprints is particularly difficult to interpret by the general public. While the research community can understand the differences and biases of non-peer-reviewed literature, the general public can have difficulties assessing preprints' quality and validity, and specific guidance has been suggested for general readership understanding and interpreting preprints (Brierley, 2021).

Can They Replace Peer-Reviewed Articles?

Several studies showed high rates of published journal papers from preprint servers, e.g., 64% (Abdill & Blekhman, 2019) and 68% (Fraser et al., 2020) for medRxiv preprints and 73% for arXiv preprints (Larivière et al., 2014). In medicine, this percentage is much smaller (around 6%) for articles related to COVID-19 (Añazco et al., 2021).

The difference between a preprint and its version published in a journal is most often peer review. Carneiro et al. (2020) used the quality of reporting tool to compare articles published in bioRxiv and their papers indexed in PubMed, demonstrating a very small difference between the two publications. Wang et al. (2021) looked at preprints and articles on the estimates of COVID-19 epidemiological parameters and concluded that the validity of these estimations in preprints was similar to those in journal articles and recommended the use of preprints in epidemic decision-making. The language characteristics of preprints also change in their transformation to journal articles, with most changes introduced by peer review related to data availability and incorporating additional sections for published papers (Nicholson et al., 2022).

A study of over 6000 preprint-publication pairs (Akbaritabar et al., 2022) showed that about 90% of the references remain unchanged from the preprint to the published versions and that published articles have 8% newly added citations. Change in the context of the reference in the article was the common reason for reference change. Research disciplines also differed in how they changed references: natural science and medical articles make the most extensive framing changes, whereas articles in engineering changed references related to methodological details. Compared to preprints with no journal pairs, preprints published in journals performed better in altmetric indicators (viewing, storing, discussing, recommending) (Xu et al., 2021).

The use of preprints is particularly challenging in creating evidence synthesis in health, such as rapid reviews. Rapid reviews serve as an evidence source for health policy decisions and practice guidelines, and the inclusion of preprints requires special attention and careful methodological work to ensure a check for preprint-publications pairs, that these are assessed for differences, and that sensitivity analyses are carried out to assess the impact of preprints on review results and conclusions (Clyne et al., 2021).

Editorial and Publication Policies of Preprint Sites

A study published by Malički et al. (2020) showed that the guidance on transparency in reporting and research integrity is not common in preprint servers, with the larger

servers doing a better job of providing such guidance. A more recent study (Hamade et al., 2022) confirmed this finding, showing that less than half of 37 analyzed preprint servers had policies for reporting funding and half had defined authorship contribution policy. Two thirds of the analyzed preprint servers use similarity check tools, but only around a third described how they check for fabrication, falsification, or image manipulation. The reporting of funding and conflict of interest seems to improve from preprints to articles in peer-reviewed journals (Itani et al., 2022). In any case, preprint servers have a chance to promote and demand accurate reporting of research, adherence to standards for research integrity, and comprehensive descriptions of rules and submission criteria (Malički et al., 2020). Doing this might raise the quality bar for and credibility of preprints.

Indexing of Preprints

Since 2021, major bibliographical databases, such as PubMed and Scopus, have been indexing preprints from specific sources: PubMed from NIH-funded grants and Scopus from SSRN, arXiv, ChemRxiv, bioRxiv, and medRxiv preprint platform. The preprints are fully indexed in PubMed and are linked to the journal publication when it occurs. However, in Scopus, preprint records are not linked to the journal publication. Instead, the link to the preprint server is provided, where journal reference is available. Additionally, preprints are not searchable but are only added in author profiles, and preprint citations are not included in Scopus existing publication and citation metrics.

Bridging the Gap

Discussions about scholarly communication are often reduced to scholarly publishing, considered the most visible and formalized subset of scientific communication, whose main features remain primarily traditional and are not managed by the scientific community. However, scientific communication refers to "any form of exchange used by scholars and researchers to participate in the elaboration of knowledge through critical discussions and conversations with fellow humans" (Guédon et al., 2019). The role of preprints in bridging the gap between scholarly communication and scholarly publishing is crucial by ensuring open access to different types of scientific output and encouraging transparent and open assessment.

Preprint (Peer-)Review Processes

Despite increasing concerns about its functioning in practice, peer review is a value that the research community fiercely adheres to and is often considered the "backbone" (Bornmann, 2015), "bedrock" (Rodriguez et al., 2006), and "cornerstone" (Pulverer, 2010) of the research system.

Often declared a "standard practice," the peer review process varies in the level of independence of the reviewers; number of reviewers; anonymity, structure, and scope of the review; adherence to the ethical values and principles; and other characteristics. It is often inefficient (slow and expensive), ineffective (in detecting major mistakes, plagiarism, and fraudulent research), subject to all types of biases, opaque, easily abused, unreliable (e.g., poor inter-rater reliability between reviewers), and without solid incentives (Ali & Watson, 2016; Ochsner et al., 2020; Rennie, 1999; Smith, 2010). Although open peer review practice offers solutions for some detected shortcomings, they are not widely adopted in the most conventional publishing landscape. Transparency of the peer review process is also promoted by recent initiatives introducing peer review of preprints, aiming to serve authors more directly, and liberating the reviewers from their gatekeeper's role.

In the world of preprints, numerous formal and informal activities regarding preprint assessment have been evolving. Preprints allow a remarkable speed in transmitting information. To increase trust in preprints, the reader should consider how much scrutiny is present and understand the various review processes a preprint may have undergone. Therefore, for the widespread adoption of preprint reviews, it is necessary to understand the diverse processes laying behind any feedback, comment, annotation, or peer review related to the preprint. For simplicity, we will use the term "review" in the following text, including all types of formal and informal feedback related to preprints.

Any helpful review of a preprint, especially those validated by a community, is advantageous because it aids authors in developing their manuscripts, increasing the scholarly work's rigor. Authors also have the opportunity for public response to criticism. The review process of preprints includes more researchers and could eliminate the underrepresentation of some geographic regions or career phases. Additionally, a good reviewer's work can be acknowledged and rewarded. Comments, annotations, and review reports can be used by journals, complement the journal's official peer review reports, and help journal editors in their decisions (Public preprint feedback – FAQ, 2022). However, ongoing development of the terminology, lack of unambiguous definitions, and the unclear distinction between different review types may be challenging for researchers and readers. Furthermore, all activities related to preprint review are strongly dependent on technological developments, primarily preprint servers.

Since reviews are frequently difficult to find and are not directly related to the preprint, ASAPbio has developed a straightforward, reader-friendly framework to categorize preprint review procedures to address the issues with preprint review terminology and improve preprint review discovery. The suggested Preprint Review Features (PReF) describes the essential components of preprint review activities (Polka et al., 2022): (1) requesting a review, (2) selection of reviewers, (3) public interactions, (4) inclusion of author response, (5) decision, (6) review coverage, (7) reviewer identity, and (8) competing interests.

More formal peer review of preprints is mainly coupled with journals that publish preprints and is led by journal editorial boards. On the other hand, reprint platforms

are developing open and more participatory peer review models, decoupling the process from a journal (Tennant & Ross-Hellauer, 2020). Different proposals have been made for alternative multi-stage peer review models, combining community discussions, comments, annotations, and a more rigorous standard peer review process. All these models are intended to avoid multiple submissions, reduce the workload of the research community, provide authors with a more diversified evaluation, speed up the publication time, and make the process more transparent (Rodriguez et al., 2006).

Preprint review (including peer review) allows the research community to communicate outside the journal organization. Preprints can also address some ethical challenges, such as academic inbreeding, collegial bias, and defamation, which are common in small scientific communities (Bennet, 2014). Additionally, preprints empower review contributions without author permission or editor invitation. In a world where publishing, review, and curation are increasingly separated, peer review needs clear expectations and processes (Polka et al., 2022). Most journal guidelines for reviewers can also be applied to preprint reviews. In addition, the ASAPbio community developed FAST (Focused, Appropriate, Specific, Transparent) principles for providing public preprint review (Public preprint feedback – FAQ, 2022):

- Focused: toward the field of study itself, rather than the people involved or the journal to which the manuscript might be submitted; paying attention to the current emphasis of the paper and its overall extent.
- Appropriate: utilizing a polite, respectful, and helpful tone; considering personal motivations as well as possible biases; maintaining honor by adhering to the standards of ethical behavior that are required in all research operations. Inappropriate conduct or criticisms should be called out.
- Specific: considering whether or not the findings are supported by data and offering the writers comments that are not only understandable but also helpful in improving their work; making a distinction between essential and non-essential alterations.
- Transparent: feedback must be posted publicly, and information must be shared about the boundaries of the expertise and competing interests, acknowledging any errors made and giving credit to any colleagues who helped with the review.

Preprint reviews often use an access-controlled forum where people can sign up to recommend and discuss submitted preprints. Reviewers self-select for submissions after going through identity and competency verification when registering for the forum, as opposed to an editor evaluating the relevant expertise of reviewers for manuscripts on an individual basis. This greatly increases the users' ability to remark on submissions, and it primarily broadens the pool of prospective reviewers from the frequently disciplinary audience of a single journal to the much larger but less closely knit scientific community of digital platform users.

Future Developments

Over several decades, the open-access movement has been trying to solve the accumulated problems of the serials' crisis. The fact is that today most of the papers published in journals are in open access, but the price the research community pays is too high (Grossmann & Brembs, 2021), making the problem of inequity even bigger (Ross-Hellauer, 2022). The turn of commercial publishers toward open access has been encouraged by European funders through Plan S principles aiming for open access to publication as a default. The open science agenda is driving more sweeping changes in scholarly communication. Haven et al. (2022) analyzed the intertwined concepts of responsible research practice, transparency, and open science, arguing that responsible research practice is focused on rigorous research, transparency on complete reporting, and open science on disseminating research. In such a context, wide adoption of preprints could help in reinforcing all three concepts: responsible research practices by exposing scientific methods before the start of the study, transparency by enabling reporting in the early phases of the study, and open science by broadening the traditional notions of publishing and publications with other types of research outputs.

The latest policymakers' recommendations recognize the efforts and contributions of the research community and propose radical changes in research assessment. In the context of the proposed changes, it is emphasized that preprints ensure faster dissemination of research results and that they should be acknowledged and promoted, respecting the principles and practices of research integrity (Permanent Representatives Committee (Council of the European Union), 2022). This could be the impetus for the changes in the existing scholarly publishing system, where the prestige of the journal/publisher and the peer review process has always been the most important criteria for perceived quality and selection of the content researchers are willing to read and possibly cite (Soderberg et al., 2020).

Preprints do not belong to a journal, and most are not peer-reviewed. Therefore, the assessment of their credibility should be based on other features that researchers consider essential. Transparency, openness, and reproducibility are the most appreciated characteristics of the research quality, according to a survey of almost 4000 researchers (Soderberg et al., 2020). Still, the underlying research content (i.e., study data, materials, analysis scripts, pre-registration, or pre-analysis) and evidence of independent verification of content and research claims (i.e., independent reproduction or independent robustness check) are not easy to find. Making such information visible by default could be one of the first steps in the future developments of preprints and preprint servers.

Preprints are deeply ingrained in the publication culture of many scientific fields, and several of the initiatives expand on these ground-breaking platforms and add new functions to them, highlighting their infrastructure-like nature. For example, preprints can be recommended, commented on, and invited for review on dedicated journal-agnostic services like SciRate and PREreview, managed by the scholarly community (Kaltenbrunner et al., 2022). Furthermore, such services can broaden their scope and provide reviews also for datasets, code, and other types of research

output. The additional advantage lies in the transparency and openness of the review process and reviews by providing visible links or "peer review" stamps.

Information on the author is also an important indicator of preprint credibility. Therefore, a conflict of interest disclosure statement, links to the author's identifiers (ORCID and Google Scholar), or the author's affiliation can testify to the author's reputation (Soderberg et al., 2020). For the increasing number of unaffiliated researchers (amateur researchers, researchers in transition, or those who have reasons not to mention their affiliations or have already retired (ElSabry, 2017)), the indicator of reputation could be their previous work available in open access.

Without access to the research data, other researchers cannot verify, confirm, and reproduce the study and its findings, new knowledge cannot be created, and discovery cannot be accelerated. Even though many journals adopted data policies and data availability statements, 93% of authors who indicated in their manuscript that they would share data upon request either did not respond or declined to share their data (Gabelica et al., 2022). Requiring that authors submit a data availability statement is insufficient to ensure data availability, and only strict editorial policies that mandate data sharing as a condition of publication appear to be effective in making research data available (McGuinness & Sheppard, 2021). The preprint landscape could offer improvements in data sharing and recognize incentives for researchers to increase their motivation to share research data in the "preprint phase" of their reporting.

New possibilities also appear in research assessment, mainly based on conventional metric indicators (journal impact factor, h-index) that use the number of citations and the number of published papers as primary factors. However, these indicators' shortcomings and misuse (measuring the impact of individual paper) have led to the need to introduce alternative metric indicators that will provide insight into research output dissemination, visibility, social outreach, usage, and research's impact on society. Altmetric data, which could include visits, downloads, and social media mentions, can also measure the impact of unconventional types of research output. Although usage metrics and users' comments are not among researchers' top priorities (Soderberg et al., 2020), displaying numbers of downloads and views, as well as users' comments (preferably identified), could serve as an indirect measure of the credibility of the published work and contribute to future citations.

Future development will also include continuous work on the quality of preprint metadata. Recommendations of the group of experts issued in July 2022 include metadata on removal and withdrawal of preprints, preprints as an article type, preprint versioning, and preprint relationship (including preprint to article matching, versions across servers/repositories, links to data and reviews) (Crossref Preprint Advisory Group, 2022). Following the Next Generation Repositories vision, this will enable the interconnection of metadata and actual content within the preprint server and with resource-oriented network services providing peer reviews, data, and software, broadening the scope of the services offered by repositories and third-party initiatives (Walk et al., 2020).

The present scholarly publishing system distorts the scholarly communication system that creates new knowledge, wrongly treating competition as the core

instrument of research management (Guédon, 2021). Decoupled from the traditional publishing system, preprints offer a dynamic landscape for development, experiments, and innovation. Focused on transparency and openness, they are fully aligned with the open science agenda. We cannot expect preprints to solve all professional, publishing, or ethical problems in scholarly communication. Still, their development led by the academic community could offer solutions for fast dissemination without restrictions and charges, broader collaboration, revised models of peer review, more incentives and rewards for researchers, open infrastructure, shared data and source code, and reproducibility. Also, they can advance equity, diversity, and inclusion in scholarly communication. Possible threats to research integrity should be concerned and carefully monitored, offering timely solutions.

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