

experience have been developed in studies involving research institutes in sending and receiving countries, e.g., the Mexican Migration Project (Princeton University), the “push and pull factors of international migration” project (a joint project of Eurostat and NIDI, Netherlands Interdisciplinary Demographic Institute), and the Migrations between Africa and Europe Project (led by INED, the French National Institute for Demographic Studies).

Training. We propose M.Sc. and Ph.D. programs in migration and population diversity. These should adopt a holistic perspective integrating demography, economics, analytical sociology, geography, cognitive anthropology, political science, and international migration law. The programs should ensure that migration issues are properly treated in the production of statistics and the formulation of policies.

Our recommendations could help expand and improve the evidence base available for public debates and policy formation. Our hope is that these debates will lead to policies to promote full participation of all population groups in society and turn diversity into a valuable asset in a globalizing world. ■

REFERENCES

1. G. J. Abel, N. Sander, *Science* **342**, 1520 (2014).
2. G. J. Abel, “Estimates of global bilateral migration flows by gender between 1960 and 2015” (Working paper 2/2016, Vienna Institute of Demography, Vienna, 2016).
3. UN, International Migration 2015 [wall chart] (UN, New York, 2016).
4. UNHCR, Worldwide displacement hits all-time high as war and persecution increase (2015); www.unhcr.org/558193896.html.
5. UNHCR, Syria regional refugee response [data portal] (2016); <https://bit.ly/RegionalResponse>.
6. UNHCR, Total number of Syrian refugees exceeds four million for first time (2016); www.unhcr.org/559d67d46.html.
7. N. Esipova, J. Ray, A. Pugliese, *Gallup World Poll: The Many Faces of Global Migration* (in cooperation with GALLUP, International Organization for Migration, Geneva, 2011).
8. Population Division, International Migration (Population Division, UN, New York, 2016); www.unmigration.org.
9. OECD, OECD migration databases (2016); www.oecd.org/els/mig/oecd-migration-databases.htm.
10. World Bank, Migration and Remittances Data (2016); <https://bit.ly/MigrationRemittances>.
11. J.-C. Dumont, G. Lemaître, *OECD Econ. Stud.* **2005**(3), 49 (2005).
12. P. Gerland, Population Division, Migration, mobility, and big data: An overview (Population Division, United Nations, New York, 2015).
13. J. Raymer, A. Wiśniowski, J. J. Forster, P. W. F. Smith, J. Bijak, *J. Am. Stat. Assoc.* **108**, 801 (2013).
14. United Nations, “Recommendations on statistics of international migration” (Statistical papers series M, no. 58, Department of Economic and Social Affairs, United Nations, New York, rev.1, 1998).
15. C. Beauchemin, Statement prepared for the Informal Hearings for High-level Dialogue on International Migration and Development, 15 July 2013, New York (International Union for the Scientific Study of Population, Paris, 2013).
16. C. Beauchemin, *Int. Migr. Rev.* **48**, 921 (2014).

10.1126/science.aaf6545

SCIENTIFIC COMMUNITY

Preprints for the life sciences

The time is right for biologists to post their research findings onto preprint servers

By **Jeremy M. Berg**,¹ **Needhi Bhalla**,² **Philip E. Bourne**,³ **Martin Chalfie**,⁴ **David G. Drubin**,⁵ **James S. Fraser**,⁶ **Carol W. Greider**,⁷ **Michael Hendricks**,⁸ **Chonnetia Jones**,⁹ **Robert Kiley**,⁹ **Susan King**,¹⁰ **Marc W. Kirschner**,¹¹ **Harlan M. Krumholz**,¹² **Ruth Lehmann**,¹³ **Maria Leptin**,¹⁴ **Bernd Pulverer**,¹⁴ **Brooke Rosenzweig**,¹⁵ **John E. Spiro**,¹⁶ **Michael Stebbins**,¹⁷ **Carly Strasser**,¹⁸ **Sowmya Swaminathan**,¹⁹ **Paul Turner**,²⁰ **Ronald D. Vale**,²¹ **K. VijayRaghavan**,²² **Cynthia Wolberger**²³

A preprint is a complete scientific manuscript (often one also being submitted to a peer-reviewed journal) that is uploaded by the authors to a public server without formal review. After a brief inspection to ensure that the work is scientific in nature, the posted scientific manuscript can be viewed without charge on the Web. Thus, preprint servers facilitate the direct and open delivery of new knowledge and concepts to the worldwide scientific community before traditional validation through peer review (1, 2). Although the preprint server arXiv.org has been essential for physics, mathematics, and computer sciences for over two decades, preprints are currently used minimally in biology.

The ASAPbio meeting (Accelerating Science and Publication in biology) was held on 16 and 17 February 2016 to explore the wider use of preprints for disseminating ideas and results in the life sciences. The ~70 invited participants included junior and senior working scientists; and representatives of public and private funding agencies, industry, databases, and scientific journals. All talks and breakout sessions were streamed over the Internet to encourage community participation, and a full record of the meeting is available (3). The meeting goals were to analyze the roles that preprints might play in communicating results in biology and to debate the potential advantages and disadvantages of greater use of preprints for the progress of science, career development, and the integrity of the scientific record. In the three sections below, three classes of attendees—academic scientists, funders, and publishers—provide their perspectives on the meeting and its outcomes.

ACADEMICS' PERSPECTIVE

J. M. Berg, N. Bhalla, M. Chalfie, J. S. Fraser, C. W. Greider, M. Hendricks, M. W. Kirschner, R. Lehmann, P. Turner, C. Wolberger

Motivated by frustrations in the slow speed of publishing (1), we and other junior and senior life scientists participated in the ASAPbio meeting. Physicists have embraced sharing their work as preprints for 25 years. Paul Ginsparg, founder of arXiv, described how physicists, mathematicians, and computer scientists check arXiv when they wake up each morning to learn about advances in their fields. Even though physicists publish their work later in journals, arXiv has become THE way to communicate new discoveries. Ginsparg also described how preprints empower younger scientists to move their work and careers forward.

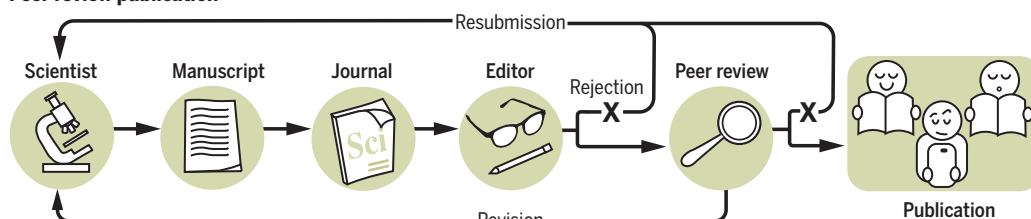
Knowledge and opinions of preprints varied among the ASAPbio attendees at the start of the meeting, but many came to appreciate their benefits. Currently, the time between manuscript submission and paper publication is unpredictable and can be long. Depositing a manuscript in a preprint archive makes the work publicly available almost immediately. Posting preprints has the added benefit of democratizing the flow of information and making it available to all investigators across the globe, while allowing journals to make their own judgments of appropriateness and interest after peer review. Publicly available preprints provide an opportunity for authors to obtain feedback beyond the few scientists who see the manuscript during peer review. Finally, preprint archives also document the history of the ideas, as old versions of a manuscript are maintained even after revisions of the work are submitted.

Ginsparg was emphatic that a preprint, because it has a time stamp and is publicly available, plays a key role in establishing priority of discovery. But will this model be widely accepted by biologists? Some suggested that the archive could be flooded with weak papers meant only to assert priority. But decades of experience have demonstrated that scientists do not post poor-quality work on arXiv because of the impact on their reputations; we expect professional biologists to behave similarly. After hearing various points of view, ASAPbio at-

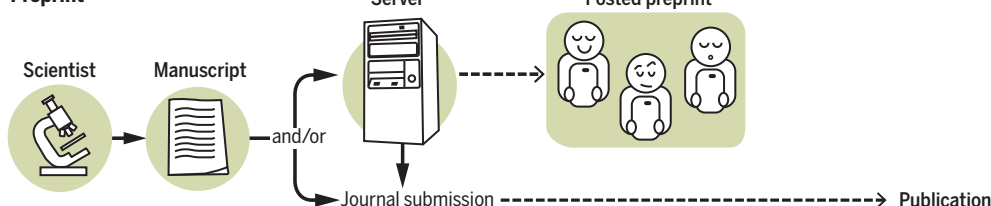
ONLINE SURVEY

Tell *Science* what you think about preprint servers at <http://scim.ag/1T5Lkfl>

Peer review publication



Preprint



Peer review and preprints. Preprints accelerate dissemination, whereas manuscripts are being improved through peer review.

tendees, in a private and optional poll, voted nearly unanimously in favor of preprints being used for establishing priority (4).

If preprints are to help early-career scientists, their use in hiring and promotion is of paramount importance. The ability to cite preprints in grant applications and progress reports would benefit scientists at all career stages. Although not peer-reviewed, a preprint provides tangible evidence of a scientist's most recent work, which is often of greatest interest to review panels. Again, by private ballot, nearly all of voting attendees thought that preprints should be considered as evidence of achievement in evaluations for academic advancement and for funding (4).

We also debated the use of preprints in reporting results of clinical studies. In its favor, some argued that clinical research would benefit from more open and timely access to data and noted that papers published in respected medical journals can also be misleading or wrong. Some who were opposed questioned whether research involving human subjects might require additional safeguards in scrutiny by institutional review boards and disclosures of conflicts of interest. As occurred in the physical sciences, different fields in biology and biomedical research may come to embrace preprint archiving at different times and to different degrees.

What would help promote the use of preprints by life scientists? Several steps are essential: broader acceptance of pre-

print posting by journals (in process and well on its way); the development of search engines for finding and linking preprints to published versions of manuscripts; and the recognition of preprints by grant, hiring, and promotion committees. These steps will likely come. But, motivated by the meeting, many ASAPbio attendees (P. E. Bourne, M. Chalfie, D. A. Colón-Ramos, S. L. Díaz-Muñoz, D. G. Drubin, M. B. Eisen, J. S. Fraser, C. W. Greider, J. K. Polka, R. Schekman, B. Stillman, R. D. Vale, H. Varmus, K. VijayRaghavan, L. B. Vosshall, C. Wolberger) are not waiting: They have taken a step toward embracing a new culture of science communication by posting a preprint this year, most of them for the first time.

FUNDERS' PERSPECTIVE

R. Kiley, C. Jones, P. E. Bourne, K. VijayRaghavan, M. J. Stebbins, J. E. Spiro, C. Strasser, B. Rosenzweig

By the end of the ASAPbio meeting, funders felt that preprints, operating in parallel with peer-reviewed publication, could play a valuable role in communicating research results.

An important issue was whether funders would recognize preprints in grant proposals and/or when reviewing the productivity of a researcher. In grant applications, funders typically ask applicants to identify relevant "peer-reviewed publications" along with the relevant persistent identifiers. Applicants are often invited to detail "other scientific contributions"—which could be used to list

preprints—but this section is typically less well-populated and may well be considered less important by external reviewers. Equally, the annual reports from funding agencies focus on peer-reviewed research outputs. However, this somewhat ambivalent approach to preprints is not the consequence of an explicit policy but rather reflects the hitherto limited use of preprints by biologists. From discussions at ASAPbio, our group of funders has identified the following benefits and challenges of preprints.

Benefits. From the perspective of a research funder, we can see substantial benefits from the widespread adoption

of preprints. Apart from the obvious benefit that research findings become available more quickly—an important consideration given data showing that the median review time at journals has grown from 85 days to >150 days during the past decade (5)—preprints provide funding agencies (and those reviewing funding proposals) with a more current and complete view of a researcher's ideas and progression of work than does a formal, peer-reviewed product of research.

Preprints enable reviewers to assess an applicant's ideas by scrutinizing the research findings, rather than using the journal name (or its impact factor) as a proxy for quality. Funders are keen to uphold the principle that funding decisions should be based on the merit of the research.

Next, preprints provide reviewers with an opportunity to see—in real time—reactions from the community and how the researcher responds to these.

Finally, preprints offer an opportunity for early-career scientists to demonstrate productivity and to provide evidence of independence. Preprints also offer more opportunity for early-career scientists to get peer feedback, especially if they lack the professional networks or the funds to attend conferences.

Challenges. The biggest challenge of using preprints to help inform funding decisions is that they represent work at various stages of development and, by extension, of varying degrees of quality. This puts even more

¹Institute of Personalized Medicine, University of Pittsburgh School of Medicine. ²Department of Molecular, Cell and Developmental Biology, University of California, Santa Cruz. ³Office of the Director, National Institutes of Health. ⁴Department of Biological Sciences, Columbia University. ⁵Department of Molecular and Cell Biology, University of California, Berkeley. ⁶Department of Bioengineering and Therapeutic Sciences, University of California San Francisco. ⁷Department of Molecular Biology and Genetics, Johns Hopkins University School of Medicine. ⁸Department of Biology, McGill University. ⁹Wellcome Trust. ¹⁰Rockefeller University Press. ¹¹Department of Systems Biology, Harvard Medical School. ¹²Yale School of Medicine, Yale University. ¹³Kimmel Center for Biology and Medicine of the Skirball Institute, Department of Cell Biology, New York University School of Medicine. ¹⁴European Molecular Biology Organization. ¹⁵The Leona M. and Harry B. Helmsley Charitable Trust. ¹⁶Simons Foundation. ¹⁷Laura and John Arnold Foundation. ¹⁸Gordon and Betty Moore Foundation. ¹⁹Nature Research Group. ²⁰Department of Ecology and Evolutionary Biology, Yale University. ²¹Howard Hughes Medical Institute and Department of Cellular and Molecular Pharmacology, University of California San Francisco. ²²Department of Biotechnology, Ministry of Science and Technology, Government of India. ²³Department of Biophysics and Biophysical Chemistry, Johns Hopkins University School of Medicine. Email: ron.vale@ucsf.edu

onus on the grant reviewers to read the preprint (as they would a peer-reviewed paper) and judge the quality and whether the conclusions reached are supported by the data presented. Even if the reviewers have all the necessary skills, reviewing preprints will add to their workload at a time when the burden on reviewers is higher than ever (6). Consequently, without careful guidance, reviewers may bias their assessment against applicants who cite material that has not yet been published in a peer-reviewed journal.

Other challenges include ensuring that preprints are easily discoverable (e.g., through services like PubMed, Scopus, and Web of Science); and remain permanently accessible. In cases where preprints are subsequently published in peer-reviewed journals, mechanisms must be established to direct the reader from one version to the other.

Recommendations. To move forward on these issues, funders should consider these:

1. Publishing an explicit statement encouraging researchers to make early versions of their manuscripts available through acceptable preprint repositories.
2. Permitting the citation of preprints in grant proposals as evidence of productivity, research progress, and/or preliminary work.
3. Providing guidance to reviewers on how to assess preprints in grant proposals.
4. Working with the community to fund a common infrastructure and standards for acceptable preprint repositories to ensure that they are easily discoverable and remain accessible in the long term.

JOURNALS' PERSPECTIVE

B. Pulverer, M. Leptin, D. G. Drubin, S. King, H. M. Krumholz, S. Swaminathan
Representatives of journals and publishers attended ASAPbio. Here we summarize pertinent points of discussion.

Preprints and peer-reviewed journals serve different purposes. The contribution of citable and stably archived preprints to scientific progress was not questioned. Preprints also represent markers of achievement and progress that can be considered in research assessment and in establishing priority of findings. This can be particularly important for young researchers who need to document progress during the early phase of their independent careers.

Some participants argued for completely replacing journals by preprint servers, noting that the extent to which peer review improves manuscripts has not been formally quantified and that peer review still misses

errors. However, the majority of attendees felt that peer review orchestrated through journals still plays a valuable role in providing in-depth analysis and scrutiny. Surveys also show that many researchers believe that their own work often improves through the peer-review process (7). Following the model of the preprint server arXiv in physics, preprints and formal papers should exist in parallel, synergizing and fulfilling complementary functions. Posting preprints facilitates the rapid communication of scientific findings, whereas peer review provides a more formal certification process that promotes reliability and reproducibility.

Many publishers support preprints, and journals could benefit. Many journals already have policies that support the posting of preprints on recognized servers before submission to their journal (8). A draft statement developed by publishers for ASAPbio stating that "Posting on a recognized preprint server does not constitute prior publication or a breach of...embargo policies..., and will prejudice neither the peer review process nor publication..." received broad approval by ASAPbio attendees (4). We also feel that comments on the preprint would help to make the subsequent formal review process more efficient and could result in an improved final manuscript. Pipelines that enable direct submission from preprint servers to journals should increase acceptance of this dual mechanism in the community.

Several issues will require further thought. A preprint creates a "date stamp" in attributing scientific findings to researchers. Premature posting to "stake claims" will need to be self-moderated by the community. Furthermore, establishing priority also will depend on credibility gained through peer review.

Preprints and published research papers represent a continuum in the evolution of a body of work and should be formally linked, such that the scientific paper supersedes the preprint as the version of record that should be cited. "Versioning" is necessary to allow preprints and papers to be adapted, both in response to further progress in the research project and in response to comments from other scientists.

Important questions are (i) whether preprint submissions should be screened for adherence to scientific and ethical standards and (ii) how to handle data that raise ethical concerns or that contravene national policy or guidance. Preprints of clinical data could be very useful, but it is essential that it be made clear, especially to the press and the public, that preprints must be formally recognized only as non-peer-reviewed units of information. Preprint archives may need to

give clear guidance to authors about such studies. Thus, citations to preprints could have a different format and be separated from citations to the peer-reviewed literature.

Optimal commenting and discussion formats on preprints remain to be defined and can range from direct communication with authors to public, signed comments.

The *raison d'être* of a preprint server is the sharing of research findings without delay, but preprints are not necessarily only an alternative or a preliminary step to publishing in formal journals. Posting of units of information smaller than research papers should be encouraged, as long as the data reporting allows others to replicate the work. The value of sharing review articles and commentaries as preprints is less clear.

In summary, if, as is the case for physics preprints, the community engages in constructive and objective discussion of preprints, both the scientific community and journals are likely to benefit directly.

CONCLUSIONS

Preprints could play important roles in accelerating scientific progress; they could serve the needs and foster the careers of scientists; and, in cooperation with existing journals, they could enhance the current system for communicating results and ideas in the life sciences. However, preprints are relatively new to biology, and many questions remain unanswered. Will funding agencies encourage the use of preprint servers? Will all journals accept manuscripts for publication after they have been disseminated as preprints? Will the life sciences community find ways to make biology preprints easily discoverable? And will researchers themselves decide to submit, cite, and evaluate work presented in preprint form? The cooperative spirit displayed by the attendees at ASAPbio gives hope that these complex issues, as well as others that limit the communication of scientific ideas and results, can be addressed in a productive and thoughtful manner. ■

REFERENCES AND NOTES

1. R. D. Vale, *Proc. Natl. Acad. Sci. U.S.A.* **112**, 13439 (2015).
2. iBiology, What are preprints? (2016); www.ibiology.org/ibioeducation/what-are-preprints.html.
3. ASAPbio, 2016 meeting (2016); <http://asapbio.org>.
4. ASAPbio, Draft document (2016); <http://asapbio.org/drafts>.
5. K. Powell, *Nature* **530**, 148 (2016).
6. M. Arns, *Nature* **515**, 467 (2014).
7. Sense About Science, *Peer Review Report 2009: Final Report* (Sense About Science, London, 2009).
8. Wikipedia, List of academic journals by preprint policy (2016); <http://bit.ly/Journalpreprintpolicy>.

ACKNOWLEDGMENTS

We thank D. A. Colón-Ramos, J. K. Polka, R. D. Vale, and H. Varmus for organizing and Howard Hughes Medical Institute for hosting ASAPbio.

10.1126/science.aaf9133



Preprints for the life sciences

Jeremy M. Berg, Needhi Bhalla, Philip E. Bourne, Martin Chalfie, David G. Drubin, James S. Fraser, Carol W. Greider, Michael Hendricks, Chonnetia Jones, Robert Kiley, Susan King, Marc W. Kirschner, Harlan M. Krumholz, Ruth Lehmann, Maria Leptin, Bernd Pulverer, Brooke Rosenzweig, John E. Spiro, Michael Stebbins, Carly Strasser, Sowmya Swaminathan, Paul Turner, Ronald D. Vale, K. VijayRaghavan, and Cynthia Wolberger

Science **352** (6288), . DOI: 10.1126/science.aaf9133

View the article online

<https://www.science.org/doi/10.1126/science.aaf9133>

Permissions

<https://www.science.org/help/reprints-and-permissions>

Use of this article is subject to the [Terms of service](#)

Science (ISSN 1095-9203) is published by the American Association for the Advancement of Science. 1200 New York Avenue NW, Washington, DC 20005. The title *Science* is a registered trademark of AAAS.

Copyright © 2016, American Association for the Advancement of Science