Recommendations to Funding Agencies for Supporting Reproducible Research

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The ASA asked these many of its members what advice they would provide to funding agencies to encourage reproducible research. The ASA shares their comments to inform discussions within funding agencies and more broadly. Our motivation is to help produce better scientific research and to highlight the role of statistics and statisticians. We do not intend these steps to be official recommendations that *must* be implemented but hope they are received as constructive contributions to the ongoing discussions.

Definitions:

We recognize the variation in definitions of terms regarding reproducible research. In this document, we adopt the following widely used definitions.[1]

1. Reproducibility: A study is reproducible if you can take the original data and the computer code used to analyze the data and reproduce all of the numerical findings from the study. This may initially sound like a trivial task but experience has shown that it's not always easy to achieve this seemingly minimal standard.
2. Replicability: This is the act of repeating an entire study, independently of the original investigator without the use of original data (but generally using the same methods).

Principles:

1. Reproducibility is enhanced by following best current practices, including:
    a. Ideally, exclusive use of publicly available data. However if the research domain does not allow for publicly available data for widely accepted reasons (e.g., medical data with high confidentiality concerns), the principles outlined in items

[1] Definitions copied from: "A Simple Explanation for the Replication Crisis in Science," Roger Peng, August 24, 2016, http://simplystatistics.org/2016/08/24/replication-crisis/.

(b) - (e) should still be followed
   b. Use of version control for all (collaborative or individual) code development
   c. Exclusive use of open-source software freely available to anyone in the world
   d. End-to-end scripting of research, including data processing and cleaning, statistical analyses, visualizations, and report and/or manuscript generation, with the full workflow made available to others
   e. Use of container/virtual machine tools to capture software versions, dependencies, and platform specifics
   f. Publication of code in public repositories as with data
   g. For projects that develop algorithms, implementing algorithms on standard computational platforms (e.g., R packages, Python packages, source code packages installable via standard methods, etc.)
2. Reproducibility shouldn't be thought of as a binary state—either reproducible or not-reproducible—but as a continuum from hard=to-reproduce to easy-to-reproduce. The goal of any reproducibility effort should broadly be to move as many people as possible further towards easy-to-reproduce. Achieving this will require both technological components (i.e., to make the right thing easier than the wrong thing) and social (i.e., to motivate people to learn a better process even though it's harder in the short-term) components.
3. In this "replication crisis" era, reproducibility is the only thing that can be effectively guaranteed in a published study. Whether any claimed findings are indeed true or false can only be confirmed via additional studies, but reproducibility can be confirmed immediately.

Observations:

1. There are several barriers to researchers making their research reproducible.
   a. Lack of skill with the available tools for reproducibility, including better programming skills and awareness of best practices and tools for reproducible research.
   b. Doing research reproducibly takes time. In a competitive environment, researchers see more benefit in working on more projects than in doing research reproducibly.
   c. Related to (b) there are limited explicit incentives to doing careful reproducible research compared with writing more papers. In some cases however, researchers may find that their work is more heavily cited and more influential when they make their code available for others to use, particularly as a general software product.
   d. Code and data are not universally recognized as research products. This results in resistance from researchers to sharing them publicly, for example, in the same way that PDFs of journal articles are shared.
   e. There is not a well-established etiquette for working with code written by others.[2] This makes some researchers anxious about making their code public

[2] "A New Etiquette for Replication," Daniel Kahneman, https://www.scribd.com/document/225285909/Kahneman-

because of the possibility of being humiliated.

2. Reasonably priced infrastructure resources exist for supporting reproducible scientific publications (e.g., github)
3. The funding model for reproducible research has not been worked out yet. In particular, if data and code are to be made available to the public in perpetuity, it is not clear who should pay for that.

Recommendations (specific to a funding agency):

1. Funding:
    a. Develop funding mechanisms to support small-scale software development and data products by researchers in domain areas rather than software developers. This might involve new development or support for software and datasets developed in the course of a grant beyond the lifespan of the grant, particularly for software and data getting traction in the community. Methodological researchers often produce small software products for which getting an entire full-size grant for software development (e.g., through the NSF SSI and ABI programs) is not appropriate. Similarly, scientific researchers may develop a data product that needs to be maintained long-term. Perhaps such smaller scale support could be done via mini-grants that a researcher can apply for as anextension to the main grant. It would not be guaranteed but would not be as difficult to get funded (similar to how having an NSF grant makes it easier to get an allocation on XSEDE.)
    b. Fund work that includes an aim to reproduce and/or replicate previous work when that previous work is sufficiently important. For example, for a proposal that proposes a new idea in area X, one aim of the grant might be to reproduce or replicate a key previous finding in area X on which the new work would build.
2. Training
    a. Provide support for the development of appropriate courses. Most students and faculty have little training in how to organize their data and software so that their analyses are reproducible.
    b. Possible training resources:
        i. University of Wisconsin Biostatistics Professor Karl Broman's course on reproducible research: http://kbroman.org/Tools4RR
        ii. Software-carpentry.org and datacarpentry.org workshops
        iii. NESCent materials for workshops focused specifically on reproducible research: https://github.com/Reproducible-Science-Curriculum/Reproducible-Science-Hackathon-Dec-08-2014
3. Incentives
    a. Consider including code management plan as part of the current data management plan section of grant proposals (but without requiring more writing in the proposal).
    b. Require reviewers of a grant proposal to make a specific assessment of the data

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Commentary.

management plan.

c. Duke has implemented reproducible research training as part of a computing bootcamp within the grad orientation for which students receive Responsible Conduct of Research credit. The credit system provides the incentive for students to take the course. Materials for this workshop are at https://github.com/mine-cetinkaya-rundel/dss_computing_bootcamp.
d. Consider ways to either increase one's chances of having a grant funded with robust and reliable science steps in the proposal or to increase the likelihood of renewals based on robust and reliable science steps in previous grant work.

4. The agency could provide guidance/best practices for what a researcher should do for their study to be seen as reasonably reproducible. See for example this Nature checklist, http://www.nature.com/authors/policies/checklist.pdf, and the beginnings of a similar (more informal) checklist put together by the University of Washington's eScience group Open Science and Reproducible Badges: https://github.com/uwescience/reproducible/wiki/%5BDRAFT%5D-Open-Science-and-Reproducible-Badges. Researchers, peer reviewers, and journal editors could also be made aware of the Open Science Framework's Badges to Acknowledge Open Practices: https://osf.io/tvyxz/.
5. Increased call for statistician reviewers where more attention to study/experiment design, analysis, inference, and uncertainty quantification would benefit the science (similar to *Science* Magazine's Statistical Board of Reviewing Editors).
6. Given the variation and disagreement in reproducible research terms, help to develop terminology to convey reproducible research concepts consistently across the scientific disciplines.