# Best practices guide in open and reproducible science

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Among the basic values of science is the idea that knowledge is part of the common heritage of humanity.[1] The advance of science depends on the validity and strength of its results as well as the possibility of independently verifying and reproducing them.

Nonetheless, the unique aspects of the scientific field set up barriers to access to and reliability in what is published. Due to an incentive system based on publication in specialized journals that are usually associated with commercial publishers, less than half of all published articles are open access.[2] An even smaller fraction of these provide all of their data for independent verification.[3,4] This may be why recent surveys in fields like psychology and biomedical science suggest that most published results are not reproducible,[5-7] which implies squandered resources and delays in advancing science.

As an institution dedicated to supporting science in Brazil, Serrapilheira reaffirms its commitment to and its expectation that findings from research funded by the institute be published in a transparent manner so that they be accessible, verifiable and reproducible. The guidelines listed below are suggestions for best practices at different stages in the scientific process to achieve these goals.

Obviously, not all the recommendations apply directly to all fields of research. Theoretical physicists and mathematicians, for instance, need not abide by matters related to conducting experiments. On the other hand, guidelines on topics such as scientific publication are valid for all fields, albeit with their own specificities.

**Knowledge is part of the common heritage of humanity.**

# Upon developing a project

## Upon developing a project

Perform a careful literature review before starting a project, be it experimental or theoretical. This step will help to avoid duplicating efforts and ensure that authorship of ideas and previous findings is duly attributed. The use of systematic review protocols with explicit research methodologies makes the process more impartial, reproducible and robust as a scientific contribution.[8]

Registering your protocol before collecting data lends greater transparency to the process and makes it possible to verify whether data collection and analysis were carried out as planned in order to differentiate confirmatory versus exploratory analyses.[9,10] Additionally, this practice makes it possible to identify recorded but not yet published studies.[11] This step is mandatory for clinical trials[12,13] and can be adopted in different ways in other fields of research. Repositories for protocol pre-registration include Open Science Framework and AsPredicted. Protocols may be made publicly available upon registration or embargoed until the data is published.

## Upon developing a project

One way of getting feedback before carrying out the study—when critiques and suggestions are more likely to have an impact on the project—is to have the protocols peer-reviewed, be it in the form of an independent article or as a preliminary submission in journals that accept the Registered Report format, where the methods are reviewed, thus providing a preliminary approval of the study should the protocol be followed, regardless of the result.[14] A list of journals that accept this format is available at the Center for Open Science.

Before collecting data, make a plan for statistical analysis that includes a sample size calculation. This avoids conducting experiments with low statistical power, which squander resources and generate less reliable results.[15] Many online calculators like Power and Sample Size easily carry out these calculations.

## Upon developing a project

When designing your project, remember to include measures and controls for obtaining robust conclusions regardless of the result. It is important to establish criteria for differentiating a “negative” result (in which a certain experimental intervention does not generate the expected result) from a flawed experiment due to methodological problems to ensure that the latter be sufficiently reliable for publication. Publishing negative results is a fundamental measure to keep from distorting scientific knowledge through publication bias.[16,17]

**Open access is essential for the advancement of Science and the reliability of its results.**

Establish a data management plan that defines where the data will be stored during and after the project. Include a strategy for copying the data to have a backup and to ensure long-term accessibility, regardless of moves between laboratories/institutions. Many repositories are available for this purpose, be they tied to specific institutions or not—a list can be seen at FAIRsharing.org. The FAPESP website also offers guidelines on how to develop a data management plan.

# Upon running experiments

## Upon running experiments

Take measures to control for bias, such as blinding experimenters regarding the identity of the groups while running experiments and evaluating outcomes. Even though the importance of these procedures has been recognized for decades, their adoption by various research areas, like laboratory science conducted with animals, is still unacceptably low for a procedure that should be common.[18]

Adopt a system for recording protocols and results, such as a lab notebook or an electronic tool that does this job. Train those in charge of data collection and make it clear that writing protocols and results down is mandatory and is the documentation of what was done and cannot be erased or adulterated. For more guidelines about laboratory notebooks, see the National Institutes of Health website.

## Upon running experiments

Try to get to know the intra- and inter-reproducibility of the methods that you use. If it has not been established, consider the possibility of replicating key data from your project among different members of your laboratory or among different laboratories. Even though it may not be possible to do this for all data, taking this step can be a valuable practice for large-scale confirmatory experiments.[19]

Establish protocols for quality control and checking common methodological errors in order to periodically evaluate the quality of the data generated. If such procedures lead to excluding data or experiments, establish criteria so that this takes place before obtaining results and explicitly mention them in your description of methods to keep these exclusions from creating bias in the results.

# Upon analyzing results

## Upon analyzing results

Keep your databases organized and document the analyses carried out, just the way you would with experimental findings. If you use your own code for analysis, make sure it is documented and understandable to third parties. Consider integrating your code with your results by using tools like Jupyter, R Markdown, knitr or Sweave, which allow you to easily repeat analyses and simulations.

When using inferential statistics, remember that this process makes presumptions about previously-established data and hypothesis—and ideally registered beforehand. We are not opposed to the use of exploratory analyses; however, they must be clearly described as such and set apart from analyses designed to test a priori hypotheses.[20] Statistical models based on the data such as those generated through machine learning must be tested in sets of data that are different from those in which they were generated in order to avoid circularity in the analyses.[21,22]

## Upon analyzing results

Avoid the common dichotomy between "significant" and "insignificant" results. If you use frequency statistics, provide exact P-values and interpret them in terms of how plausible your hypothesis and the statistical power of the experiment before considering that a result is probably true.[23,24] If you wish to express this type of logic, it can be formalized in Bayesian analyses that take the a priori probability attributed to a hypothesis into consideration.

Keep in mind that statistical significance and magnitude of effect are different concepts and consider alternatives for clearly expressing either of these qualities upon presenting your data, such as using the measurement of the impact associated with confidence intervals.[25]

Regardless of the results of your analyses, keep in mind that any inference based on a sample includes the possibility for error. Be candid in exposing the question both in terms of positive and negative results and address the limitations of your methods and analyses in discussing your results.

**Science is a practice that needs constant review**

# Upon publishing results

## Upon publishing results

Use open access platforms for publication. These may include open access journals (gold open access) as well as placing versions of your articles in public repositories (green open access). For more information regarding open access, visit Budapest Open Access Initiative and cOAlition S. Regarding the green route, most publishers have policies that are compatible with the depositing of pre- and post-print versions — to check the polices of a particular publisher or journal, visit SHERPA/RoMEO. Upon publishing or depositing an article, use sharing options that guarantee that the article can be used and redistributed, such as the licenses at Creative Commons.

Should you choose open access journals that cover the publication fees (emphasizing that this is not the only way of guaranteeing open access), aim to make sure that said journals have a real peer review system and that they do not fall under the category of “predatory journals.” A list of open access journals that meet the minimum quality control standards can be found at Directory of Open Access Journals.

## Upon publishing results

Deposit your articles as preprints before or upon submitting in repositories such as arXiv, bioRxiv, chemRxiv, PsyArXiv, medRxiv and others (a wide-ranging list is periodically updated at Research Preprints). Using preprints accelerates the scientific process and is compatible with submitting articles to most journals (to search specific policies, see SHERPA/RoMEO ou a Wikipedia). After the peer review, update your preprint so that it is as close to the final publication as possible—this will also act as a way of reaching green open access.

Citing preprints in scientific articles and commenting on preprints (i.e. post-publishing peer review) is also encouraged. Furthermore, preprints must be considered to be valid scientific production for evaluating projects and researchers. For more information about preprints, especially in the field of life sciences, visit ASAPbio.

## Upon publishing results

Describe your methodology as broadly as possible so that other researchers can replicate your results. If the journal has space restrictions, use complementary information or deposit the protocol in a repository, ideally using platforms specifically-made for this purpose like protocols.io. If there are reporting guidelines for your field of research, use them as a checklist on what needs to be described. For a collection of guidelines in the field of the health and life sciences, visit Equator Network.

Fully share the data from your research upon submitting your article. The data can be included as complementary material or be deposited in repositories, be they those of your institution, general repositories (e.g. Zenodo, Dryad, figshare, Dataverse) or platforms that specialize in a specific type of data. A list of repositories by area is available at FAIRsharing.org. If there is consensus about standardizing data in your field, you should adopt those structured formats. Otherwise, include a manual describing data and metadata that make them accessible for automated searches. In any case, make sure that your data have a DOI for citation. Merely stating that data is made available by contacting the authors is insufficient since such a practice does not guarantee access. [27,28] For more information about the principles of depositing scientific data, see FAIR principles.

**Less than half of all published articles are open access**

## Upon publishing results

When it comes to sensitive data that cannot be shared in full such as personal information of volunteers or data that requires protection due to intellectual property issues, consider whether this data can at least be made partially available (e.g., by removing information to guarantee volunteers' anonymity) or after an embargo (e.g., after the intellectual property is established). For more information about data privacy, see the Brazilian General Law for Data Protection and the guidelines of the European Commission regarding the protection of data used in research.

Should your research study use code developed by you or a third party, include it as complementary information or deposit it in a repository like GitHub. Prioritize open code languages like R or Python, but make your code available even if you work with a proprietary language. Again, consider integrating the code into your results with tools like Jupyter, R Markdown, knitr or Sweave. Cite third-party codes and databases with their respective DOIs in your research in order to recognize them as valid forms of scientific production.

## Upon publishing results

Attribute the authorship of publications in a way that is fair and compatible with the criteria of your field of research. Even though these may vary depending on the field, general guidelines can be found at Comittee on Publication Ethics (COPE), and several areas and journals use the criteria of theInternational Committee of Medical Journal Editors. For greater clarity, we recommend that the contributions of each author be detailed in a separate section, ideally using standardized taxonomies like those of CRedIT.

If you have any conflict of interest related to your results—be it financial or otherwise—be transparent by stating it by publishing and presenting the conflict(s). Although conflicts of interest are inevitable at times, the effort made to minimize them contributes to the impartiality and integrity of your research findings. For more information and definitions regarding conflicts of interest, visit COPE.

# Always

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Engage in discussions about open and reproducible science, especially when it comes to training new scientists. Provide your students and collaborators with guaranteed incentives and make it clear to them that you value them for the effort and rigor they invest in the research and not for the result obtained. Raise issues related to scientific reliability in discussions with your research group and institution and stay connected to literature on this topic.[29,30]

When evaluating your peers as an editor, reviewer, dissertation committee or evaluator, bear in mind the evaluated researcher's scientific rigor, transparency and commitment to open science. Be skeptical and consider whether the results you are evaluating are solid and reliable before asking about their impact.

## Always

Consider science to be a practice that need constant review. Appreciate, discuss or perform repeat and confirmatory studies in your field of research.[31] Register and publish your attempts at replication, regardless of whether they are successful (or not). Stay engaged in the practice of evaluating published science by participating in for a for post-publication review like PubPeer, and the comment sections of journals and preprint repositories. When considering taking on the role of a reviewer for journals, prioritize those that make revisions available,[32] be they attributed to an author or anonymous. Be courteous and respectful at all times by giving constructive criticism that contributes to the advance of science.

Likewise, be open to criticism from colleagues and do not see the critiques of your data as personal attacks. Be open to the possibility of correcting and reanalyzing your data by collaborating with your critics whenever possible. If mistakes or inconsistencies are found, be transparent when admitting them and use the mechanisms in place for making corrections and retractions in the literature. Remember that admitting mistakes honestly is not a blemish on the researcher's reputation and that the ethical consequences of not correcting them are more serious.[33]

**Engage in discussions and trainings about open and reproducible Science**

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