

F1000

How to make your research more reproducible

Explore these actionable tips to help you improve reproducibility

Introduction

A lot has been said in recent years about the so-called **reproducibility crisis in science**—is there a ‘crisis’ and, if so, how do we go about rectifying it?

At a time when trust in science and evidence has and continues to be tested like never before, integrity and reproducibility in research are critical. From a publishing perspective, it is clear how supporting open practices such as data sharing, registered reports and publication of both positive and negative results can help to overcome the challenges of the reproducibility crisis. The more widely these practices are adopted across all research disciplines and geographies, the stronger our scientific understanding, and public trust in it, will be.



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Researchers, publishers, and funders all have a role to play in increasing the reproducibility of research. Read on to learn what you can do **today** to do your part in creating reproducible research.

Tackling the reproducibility crisis

Accuracy and reproducibility are essential for fostering robust and credible research and for promoting scientific advancement. Reproducibility demonstrates that research results are objective and reliable and not due to bias or chance. Yet, researchers are increasingly discovering studies that are either difficult or impossible to replicate.

Science, in general, is facing challenges in one of its basic tenets: replication. Significantly, [one study](#) revealed that in biology alone, **over 70% of researchers could not reproduce the findings of other scientists**, and approximately **60% of researchers could not reproduce their own findings**. But biology isn't the only discipline where the question of reproducibility is in the spotlight. Replication projects in psychology, medicine, behavioral economics, genetics, and neuroscience have raised questions around the validity of existing studies.

How can we make research more reproducible?

Producing reproducible research is a process that begins in the planning stage of a research project and carries through all the way to publication. By consistently following the recommendations described in this guide, you can increase the reproducibility of your work, help safeguard scientific rigor, and build trust in science.

#1 Additional training in rigorous research practices

It is critical that research methodology is thoroughly described to help improve reproducibility. Poor research practices can cause irreproducibility, such as unclear methodologies, inaccurate statistical or data analysis, and insufficient efforts to minimize biases. Poor study design also makes it less likely that research will be reproducible.

However, **you can boost the validity and reproducibility of your research simply by undertaking additional training** in statistical methodology, data analysis, detailed reporting, or experimental design. Training can help you ensure you are structuring experiments objectively, depicting your results accurately, and performing statistical analysis to the highest standards.

Moreover, to work in a reproducible manner, you could **seek out opportunities to develop new skills**, such as learning how to use new software and tools, developing data and software engineering skills, and becoming an expert project manager. You can seek out relevant training and professional development courses, by connecting with senior colleagues, your institution's librarian, and your institutions postgraduate research centre if they have one.



#2 Sharing data, software, materials, workflows, and other tools

One of the most basic barriers to reproducibility is data unavailability. If the original data set is not openly available, independent analysis cannot be performed. **To reproduce published work, researchers need to access the original data, protocols, and key research materials.** Without access to all the research outputs, researchers are forced to reinvent the wheel while they attempt to repeat previous work making reproducibility near impossible.

Some researchers resist sharing their data and research materials due to the fear of scooping by other researchers. However, **you can share your data for reuse without fear of scooping by publishing your data in a repository**, such as [Figshare](#) or [Code Ocean](#). An open access data repository is a place for researchers to deposit and store research datasets. Repositories create a Digital Object Identifier (DOI) that enables your research to be more readily discovered and cited.

By depositing your data in repositories, you allow your data, code, and other tools to be reused. These repositories store data in a way that allows immediate user access to anyone, so there are no access restrictions. Additionally, if you describe your data with rich, meaningful, machine-readable metadata, you make it easier for other researchers to find and replicate.

Many open access publications now enforce data sharing policies that require authors to share their data via a repository. We suggest choosing a repository that is suited to your research topic. You can search for a suitable repository on [FAIRsharing](#) and [re3data.org](#).



#3 Publishing research intent before research begins

In some areas of research, notably in the health and psychological sciences, researchers are increasingly publishing their study designs and hypotheses prior to undertaking the research by [registering study hypotheses and protocols](#). The goal of this is to provide greater transparency and to eliminate poor research practices, such as hypothesizing after the results are known ([HARKing](#)) and [cherry-picking](#) results to 'create' or exaggerate significance.

Public registration of hypotheses and protocols can safeguard the integrity of results by establishing the priority of a research approach. This increases the quality of study design and the reliability and reproducibility of results. It also provides a solution to the phenomenon of publication bias—where the decision to publicize or disseminate research is based on the perceived significance or interest of the results.

Moreover, registration is the first step towards trial transparency and ensures that research decisions are informed by all of the available evidence, thus, overcoming publication bias and selective reporting. Additionally, **registration also provides opportunities for collaboration and reduces duplication of research efforts.** To make your research more reproducible you can publish your research intent in [Study Protocols](#) and [Registered Reports](#).

Publishing proposed research studies prior to initiating a study allows reviewers to evaluate and verify your research approach. In turn, this helps make sure the research is reproducible by ensuring that the research information gathered, interpreted, and reported is unbiased and easily replicated by other researchers.



#4

Widen access by publishing open access

Another challenge for reproducibility is the lack of transparency and accessibility. Advancing knowledge is critical to the ethos of scientific research. Yet, research findings are often hidden behind paywalls limiting access to a select few. Research processes and workflows are also hidden making it hard for others to judge the credibility of research.

This is problematic for reproducibility because it's essential that everyone can access research so that it can be replicated and verified. To counter this, and help demystify scientific research, you can **publish the full story of your research open access via a wide range of article types**. This lets other researchers, the public, policymakers, and peer reviewers readily access and assess your research claims and supporting evidence. This helps increase the reproducibility of your research because other researchers across disciplines and specialties can trust your findings and create study designs that cite and build upon your findings.

Moreover, if a study does not rigorously detail study design, underlying data, reference materials, and laboratory protocols, it becomes very hard to reproduce. If other researchers don't know how you reached your findings, they won't be able to check that they are correct, which means they won't be able to validate your research. As such, **publishing your research in a fully open access publication, where other researchers can read, use, and share it is critical to increasing the reproducibility of your research**.



#5 Publish negative data and confirmatory results

Both positive and negative (or null) results are essential for the progress of science. However, there is a general reluctance to publish negative results due a range of factors. **In academia, industry, and across institutions, the pressure for researchers to publish is immense.** Whether the pressure to publish comes from a desire to get more funding, secure your job, enhance your reputation in your field, or if you want to get published, the work often needs to be original, novel, impactful and most importantly, statistically significant.

The preference towards positive results also stems from university hiring and promotion criteria, where emphasis is placed on publishing in high-impact publications. As a result, researchers aren't typically rewarded for publishing negative or null results. Instead, researchers are rewarded for publishing novel findings in the form of higher volumes of citations. This makes it challenging to encourage researchers to go to the extra effort of reproducing research and leads to an under-reporting of studies that produce seemingly insignificant results. As such, **reproducibility in research is hindered by the under-reporting of studies that yield negative or null results.**

This barrier to reproducibility is further compounded by the competition researchers face to secure research grants. The importance placed on positive results may inadvertently incentivize researchers to avoid repeating negative work that may be difficult to replicate if they believe they are more likely to receive funding.

By publishing your negative and null results **you prevent other researchers from wasting funding and resources trying to replicate studies that cannot be reproduced.** Your negative findings can also **lead to new discoveries** as others cite your research and adjust their experimental design based on your findings.



#6 Value researcher behaviors as well as researcher outputs

Over recent years, there have been an increase in studies **suggesting** the pressure to produce significant research outputs promotes questionable research practices. This leads to questionable data and hindering reproducibility.

Patients, funders, the public, academia, and researchers themselves are heavily invested in research outcomes as new discoveries lead to improved treatments and quality of life. This places high expectations on researchers to publish significant results. However, the pressure to publish novel research and the challenges faced by researchers when trying to secure funding means that many depend upon their research generating exciting findings. As a result, researchers may engage in certain practices to boost the likelihood of significant results. This undermines reproducibility as it can lead to inflated false-positive results and diminishes the quality and integrity of research findings.

Everyone involved in the research ecosystem can help emphasize the value of behaviours such as, evaluation, learning, and accountability, in academic research. However, **you can take the first step by sharing your experiences with your peers, whether it be how you evaluated your research and what lessons you learned.** This way other researchers benefit from your shared experiences and won't make the same mistakes again.

Furthermore, at the end of your project, you should look back at your research and reflect on how you planned for and managed the ethical implications of your work. There may have been problems that you did not anticipate, or your work may have had an impact that you did not predict. **Record what you think went well, what you found difficult, and what you would do differently if you were to repeat the same research.** You should share and discuss this with peers and in your published research so others can learn from and build upon your research. **By actively performing these behaviours, you help increase reproducibility by safeguarding research integrity.**

#7

Incorporating new technology and tools into existing workflows

Another way you could help champion reproducibility is by using new technology and tools to share your research data. Laboratory researchers are increasingly using Electronic Laboratory Notebooks (ELNs) to record and access notebook entries. Recording, accessing, and preserving paper records can be slow, inefficient, and difficult to integrate with modern computer-controlled data capture systems. Alternatively, ELNs allow researchers to digitize their lab entries so they sit seamlessly alongside research data. This makes it easier for researchers across experiments to readily access, use, and share notebook data and quickly interpret meaning from results. This also helps facilitate reproducibility across experiments.

Moreover, **by sharing your laboratory entries digitally you allow for reproducibility at scale by facilitating multidisciplinary research.** ELN entries contain important research metadata. By letting other researchers from diverse disciplines access, use, and share your laboratory data, you facilitate the transfer of vital experimental details across different research groups.

Furthermore, **version control is an excellent tool to use to increase the reproducibility of your data and code.** It's difficult to reproduce research when data is disorganized or missing, or it's impossible to determine where or how data originated. Using version control will allow you to better manage your files. What's more, by sharing multiple versions of your research, you keep a record of how your data and code evolved over time. This allows other researchers to access, analyze, and reuse your data or code at a specific point in time enabling greater reproducibility.





Researchers, academic institutions, publishers, research funders, and policymakers all play a role in improving the reproducibility and replicability of research. But that responsibility begins with researchers making their research intent, manuscript, and data openly available.

Other important steps you can take include clearly and accurately describing research methods, conveying the degree of uncertainty in results, properly using statistical methods, sharing your data for reuse, actively conducting research in an ethical way, adopting new technologies that allow for more efficient data sharing and file management, and publishing negative or null results open access.

By consistently following the recommendations described in this guide, you can **increase the reproducibility of your work, help safeguard scientific rigor, and build trust in science.**

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F1000 fosters a culture of transparency, reproducibility, and editorial rigor, to help put your research in the hands of those that can shape the future.

Our publishing model combines the speed of preprints, with the benefits of full publication. This includes functionality that ensures the robustness, quality, and reproducibility of research using rigorous editorial checks, open data, and invited open peer review.

Explore how open data can help you **increase the reproducibility** of your research.

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