Eleven Strategies for Making Reproducible Research and Open Science Training the Norm at Research Institutions

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Abstract

Across disciplines, researchers increasingly recognize that open science and reproducible research practices may accelerate scientific progress by allowing others to reuse research outputs and by promoting rigorous research that is more likely to yield trustworthy results. While initiatives, training programs, and funder policies encourage researchers to adopt reproducible research and open science practices, these practices are uncommon in many fields. Researchers need training to integrate these practices into their daily work. We organized a virtual brainstorming event, in collaboration with the German Reproducibility Network, to discuss strategies for making reproducible research and open science training the norm at research institutions. Here, we outline eleven strategies, concentrated in three areas: (1) offering training, (2) adapting research assessment criteria and program requirements, and (3) building communities. We provide a brief overview of each strategy, offer tips for implementation, and provide links to resources. Our goal is to encourage members of the research community to think creatively about the many ways they can contribute and collaborate to build communities, and make reproducible research and open science training the norm. Researchers may act in their roles as scientists, supervisors, mentors, instructors, and members of curriculum, hiring or evaluation committees. Institutional leadership and research administration and support staff can accelerate progress by implementing change across their institutions.

Keywords: reproducible research, scientific rigor, transparency, teaching, hiring, curriculum design, open science, higher education, institutional actions

Introduction

In recent years, awareness of the importance of reproducible research and open science has grown in the research community. The importance of conducting robust, transparent, and open research has especially been highlighted by the reproducibility crisis, or credibility revolution [1–3]. Reproducible and open science practices increase the likelihood that research will yield trustworthy results, and facilitate reuse of methods, data, code, and software [4–7]. Across fields, definitions of “reproducible” and “open” may vary. While some use the terms interchangeably, in other fields “reproducible” includes elements of scientific rigor and research quality, whereas “open” simply refers to making research outputs publicly accessible. Overall, these practices seek to improve the transparency, trustworthiness, reusability, and accessibility of scientific findings for the research community and society [8–12]. Despite these developments, reproducible research and open science practices remain uncommon in many fields [13–17].

According to the 2020-2021 EUA Open Science Survey, 59% of the 272 European institutions surveyed rated open science's strategic importance at the institutional level as very high or high [18]. The strategic importance of open science has also been recognized by policy-makers, e.g. by the UNESCO Recommendations on Open Science [19]. However, effective education and training programs that teach reproducible research and open science skills have not yet been implemented across research fields. Researchers in various disciplines are discussing whether these concepts apply, and how they might be implemented. To explore these ideas, German Reproducibility Network (GRN) members organized a virtual brainstorming event (described below) to discuss strategies for making reproducible research and open science training the norm at research institutions in Germany and beyond.

The first section of this paper provides a brief overview of eleven strategies that were derived from the event. Members of the research community can implement these strategies by taking action in their roles as instructors, researchers, supervisors, mentors, members of curriculum or hiring and evaluation committees, or as part of institutional leadership, research support or administrative teams. The second section of this paper lists a few tips for implementing each strategy. Cited resources provide additional insights for those interested in pursuing specific strategies. While making reproducible and open science training the norm might involve major changes at institutions, this journey starts with small steps towards reproducible and open science practices. Changing norms will require a broad coalition; hence, we hope that this piece inspires others to join this effort, while encouraging those who are already engaged to think creatively about opportunities to enhance the impact of their work.

Event Format

In March 2022, 96 participants, consisting mostly of members of initiatives and organizations belonging to the GRN and other researchers based in Germany, took part in the virtual brainstorming event. Participants came from a variety of professional backgrounds (e.g., academic researchers, administrators, library and information science professionals), career stages (from graduate students to senior group leaders), and disciplines (e.g., psychology, biomedical sciences). The virtual brainstorming event unconference format has been explained previously [20]. The supporting information (S1 text) provides details of this specific event. This paper shares lessons learned from two days of intensive discussions, through virtual networking events, virtual meetings, and asynchronous conversations on an online discussion board.

Strategies

The eleven strategies derived from the event discussions fall into three categories: (1) offering training, (2) adapting research assessment criteria and program requirements, and (3) building communities. Figure 1 illustrates these strategies, and highlights stakeholder groups that can directly contribute to each strategy or amplify the efforts of others. The stakeholder groups examined include instructors, researchers, supervisors, mentors, members of curriculum or hiring and evaluation committees, institutional leadership, and research administration and support staff.

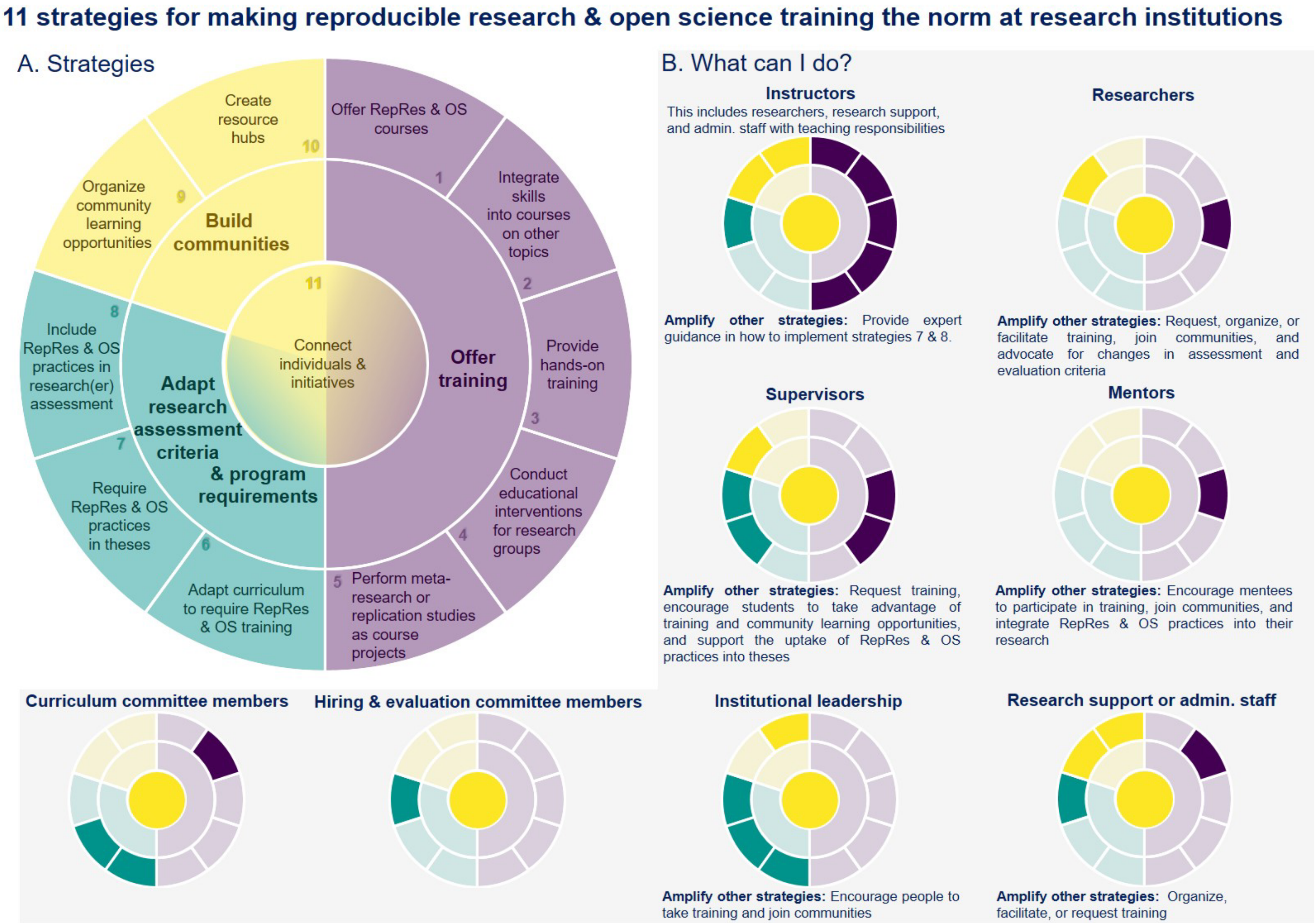

Fig.1 Eleven strategies for making reproducible research & open science training the norm at research institutions
The eleven strategies are concentrated in three areas: (1) offering training (purple), (2) adapting research assessment criteria and program requirements (cyan), and (3) building communities (yellow). While Strategy 11 is part of the "build communities" category, it is placed at the center to highlight the importance of building connections with others working on strategies in other areas (A). The small multiples (small versions of the main graph) highlight the strategies that different stakeholders can directly use at their institutions. The text

below describes opportunities for different stakeholder groups to amplify or support the efforts of those working on other strategies (B). While the roles are briefly defined below, these general definitions may vary by country, field, or institution. The figure provides a high-level overview; however, the strategies that are most relevant to a particular individual may diverge from what is shown depending on his or her specific responsibilities and activities. Many individuals fulfill multiple roles.

Definition of roles: Instructors include researchers and other staff who teach courses or provide hands-on training. **Researchers** include more established scientists, early career researchers (ECRs), research trainees, and others who design and conduct research studies. **Supervisors** provide guidance and advice on the student's research activities, but also take part in the examination and evaluation of the student's progress and performance. **Mentors** support the career development of less experienced researchers by meeting regularly with mentees to share advice, perspectives, and skills. **Curriculum committee members** serve on committees that design and/or approve curriculum for degree programs. **Hiring and evaluation committee members** serve on committees that hire, assess, or promote researchers. **Institutional leadership** includes those in high-level positions who set priorities and establish policies for the institution (e.g. dean, provost, department chair). **Research support or administrative staff** may include librarians, information technology professionals, data stewards, core facility staff, open science officers, staff working with regulatory committees (e.g., ethics committees or institutional animal care and use committees), and others who support researchers.

Abbreviations: RepRes, reproducible research; OS, open science.

Offer Training

Strategy 1 - Offer reproducibility and open science courses: This was the most common activity that event participants engaged in. Formats included single lectures, webinar series, (half-)day or multi-day workshops, summer schools, and courses [21]. While training was occasionally integrated into undergraduate or graduate curriculum requirements (see strategies 6 and 7), most courses were electives, often run by early career researchers (ECRs) for other ECRs. Some instructors offered field-specific training, while others addressed multidisciplinary audiences.

Many pre-existing examples of this format are open access (e.g. https://www.repro4everyone.org/resources, [22]; therefore, we encourage readers to search for examples that are relevant to the course formats and topics that interest them.

Strategy 2 - Integrate reproducibility and open science skills into courses on other topics: Even when reproducible and open research skills are not part of the official curricula, instructors who teach required courses on other topics can integrate reproducible research and open science skills. This might include giving a lecture on the implications of the reproducibility crisis and potential solutions in an introductory class, integrating pre-registrations into research project courses, using open science tools to analyze and present data during undergraduate practical training, or practicing techniques for writing reproducible protocols in laboratory sessions. In seminars, participants can critically debate whether selected publications fulfill necessary quality standards.

One example is the peer review training course Peerspectives [23], which integrates reproducibility and open science topics by encouraging students to examine and comment on which reproducible research and open research practices were applied in the papers that students peer review.

Strategy 3 - Provide hands-on training: Traditional courses and workshops often cover many practices in a short time; hence, participants need to decide which practices to implement, and how to implement them, after returning to their research group [24]. In contrast, participants in hands-on courses implement practices in their own research during training. After completing training, students have direct evidence that they have implemented what they learned.

One example is ReproducibiliTeach (https://www.youtube.com/@reprodubibiliteach), a flipped course where participants watch brief videos introducing reproducible research practices prior to class. During class, participants directly implement what they have learned in their own research. Book dashes and hackathons, such as those organized by ReproHack, also provide hands-on training. These can be offered as standalone events or integrated into traditional courses (https://www.reprohack.org/, https://the-turing-way.netlify.app/community-handbook/bookdash.html).

Strategy 4 - Conduct educational interventions for research groups: Implementing reproducible research and open science practices often requires collaboration among members of a research team. Researchers who completed a course independently may have difficulties convincing other members of their research team to invest time and resources into learning and adopting new practices [24]. In contrast, interventions designed for research groups may facilitate change by ensuring that all team members receive the same training and can collaboratively implement new practices.

For example, research groups can incorporate open data practices into their everyday research routines by completing a multi-week intervention that includes regular group meetings and a reading list [25].

Strategy 5 - Perform replication or meta-research studies as course projects: Rather than teaching reproducible research or open science skills that researchers can use in their project (e.g., use of reporting guidelines, open data), this approach trains participants to conduct meta-research (science of science) or replication studies. As the class collaborates on one project, participants also build skills for collaborative team science and gain experience leading small teams. Examples include conducting a replication study with students to teach longitudinal data analysis techniques (https://www.youtube.com/watch?v=NswZ6PqsHbU,[26], teaching replications in social sciences [27], or leading a participant-guided "learning-by-doing" course in meta-research, in which a multidisciplinary team of ECRs from different universities works together to design, conduct, and publish a meta-research, or "research on research", study [28]. Resources for those interested in adopting this approach include methods for running these courses (e.g.,[28,29] and studies performed by course participants [26,30,31]. An alternative approach is to have undergraduate students conduct direct or conceptual replications as thesis projects [32].

As a research group-based alternative to this approach, research group leaders or project supervisors can provide hands-on training in implementing reproducible research and open science practices in ongoing projects. Another approach is to complete a collaborative thesis. Here, undergraduate students from different universities collaborate on one project to increase sample size and statistical power [33,34]. In these cases, reproducible research and open science practice may be applied while conducting traditional research, as opposed to meta-research or replication studies.

Adapt Research Assessment Criteria and Program Requirements

Strategy 6 - Adjust curriculum to require reproducibility and open science training: Required courses reach more students than elective courses; hence, integrating courses into a required curriculum is an important step towards making reproducibility and open science training the norm. This could include adding or expanding research methods courses to cover topics such as protocol depositing, open data and code, and rigorous experimental design.

One example for undergraduate students is the Munich core curriculum for empirical practice courses. This requires that topics such as sample size planning and power analysis, preregistration, open data, and reproducible analysis scripts be included in all empirical practice courses in the bachelors curriculum at the department of Psychology at LMU Munich [35,36] see Empra slides, https://www.fak11.lmu.de/dep_psychologie/studium/lehrelounge/kerncurriculum_empra/index.html). Courses on research methods and evaluation were included in Psychology Master's programs to teach basic statistical skills and more advanced topics, such as selection bias and meta-analysis (e.g., Goethe University Frankfurt am Main, https://pandar.netlify.app/lehre/).

For graduate students, open and reproducible research practices may also be incorporated into existing required training on research integrity or good scientific/clinical practice. For example, PhD candidates may be required to attend a good scientific practice course prior to finishing their work (e.g., at the Faculty of Psychology at the Technische Universität Dresden, https://tu-dresden.de/mn/psychologie/postgraduales/promotion?set_language=en). Sometimes these courses only cover research misconduct; it is important that courses also address reproducible research and open science practices. Collaborative Research Centers funded by the Deutsche Forschungsgemeinschaft (German Research Foundation, DFG) may require PhD students to attend workshops on good scientific practice, research transparency, and research data management. This training can be accompanied by locally organized lectures and meetings on open science (e.g., at the CRC 940 of the Technische Universität Dresden, https://tu-dresden.de/bereichsuebergreifendes/sfb940/research/z-zentralprojekte/mgk).

Strategy 7 - Require reproducible research and open science practices in undergraduate and graduate theses: Degree programs may require reproducible research and open science practices in undergraduate or graduate theses. Requirements will depend on the field and program, as illustrated in the examples below.

In Germany, psychology departments have taken on a leading role in implementing this strategy. Many departments (e.g., Department of Social Psychology at Trier University, Department of Psychology at Saarland University, Faculty of Psychology at Technische Universität Dresden) already include guidelines or guiding principles on quality assurance and open science practices in thesis agreements for Bachelor's and Master's programs (https://www.uni-trier.de/fileadmin/fb1/prof/PSY/SPS/02_07_2021_Portfolio_Qualifikationsarbeit_Sozialpsychologie.pdf, https://tu-dresden.de/mn/psychologie/die-fakultaet/open-science/osip-research-transparency-statement, http://www.uni-saarland.de/fak5/psy/2022_Open_Science_Psy.pdf).

Reproducible research and open science practices have also been included in PhD thesis agreements. For example, the department of Psychology at LMU Munich requires PhD students and their primary supervisors to agree on a list of planned open science practices (e.g., open access, open data, or preregistration) before starting the thesis. All implemented practices are described in a disclosure form, which is submitted with the completed PhD thesis (https://www.fak11.lmu.de/dep_psychologie/osc/dissertation_agreement/index.html). PhD students in the Department of Psychology and Sport Science at the University of Münster need to submit a similar disclosure form with their thesis (https://www.uni-muenster.de/imperia/md/content/fb7/promotionsseite/frm_eigenanteil_20190212.pdf).

An alternative approach is to encourage students to conduct replication studies, evidence synthesis, or meta-research as part of graduate theses. In epidemiology, for example, students routinely conduct a systematic literature review as part of their PhD. Graduate programs that adopt this approach need to recognize these types of studies towards graduation requirements.

Strategy 8 - Include reproducible and open science practices in research(er) assessment: Traditional assessment criteria for hiring and evaluation of individual researchers still focus on third-party funding and the number of publications. Unfortunately, these criteria do not incentivize or reward reproducible research and open science practices. Furthermore, this approach can encourage researchers to publish more at the expense of research quality [37–39]. A growing number of coalitions and initiatives are under way to reform the way we assess research(ers) (e.g., CoARA: https://coara.eu/about/, DORA: https://sfdora.org/read/, LERU: https://www.leru.org/, European Commission [40]. Some institutions and departments have begun incorporating reproducible and open science practices in hiring and evaluation processes (https://www.gleichstellung.uzh.ch/de/projekte/hi_frame.html, [41–44]. The growing list of academic job offers that mention open science contributions [45] suggests that research(er) assessment practices are beginning to change. However, only a few institutions have released official policies on the inclusion of reproducible and open science requirements in academic job descriptions and hiring processes. For instance, the department of Psychology at LMU Munich asks professorship applicants to include a statement on how they have already implemented and plan to further implement open science practices (https://www.fak11.lmu.de/dep_psychologie/osc/dissertation_agreement/index.html, [46] There are concrete proposals on how to implement responsible research assessment, such as establishing a minimum methodological rigor threshold that candidates need to pass in order to be considered for hiring and promotion [47,48].

Build Communities

Strategy 9 - Organize journal clubs and other community-learning opportunities: Community meetings can be easy to join and help participants gain knowledge on open science and reproducible research practices, while building a network. Formats include journal clubs, open science meetups or working groups, hacky hours, coding clubs, community-driven projects (e.g., [49], open science pedagogical communities, and communities of practice. Journal clubs and other community activities are often organized by ECRs, for ECRs. Some of these formats can be implemented with a basic understanding of reproducible research and open science practices, and require comparatively little infrastructure. Researchers can also incorporate materials on reproducible research and open science in existing journal clubs, meetups, or working groups.

There are many examples of initiatives that offer community-learning opportunities; we recommend searching for initiatives that align with one's interests and desired format. Organizations such as ReproducibiliTea help scientists set up local journal clubs by providing reading lists and instructions on how to start and run a journal club [50,51]. This model has been used to establish over 100 journal clubs in 22 countries, as of February 2023. The Framework for Open and Reproducible Research Training (FORRT) pedagogical community facilitates collaborative development of educational materials [52,53], provides a starting point for adopting improved research and pedagogical practices [54], and offers a supportive environment for scholars to share experiences and lessons learned [55,56].

Strategy 10 - Create resource hubs: Resource hubs focusing on reproducibility and open science can be excellent tools to advocate for these practices while building communities. Resource hubs can serve numerous functions. For example, they can be a central hub for collecting resources, or providing training and consulting services for an institution or network. Hubs can also coordinate data collection and benchmarking activities, such as launching a survey to understand existing practices at an institution. Additionally, resource hubs can strengthen local science improvement communities by helping to implement other strategies described above.

Resource hubs include Open Science Centers, Open Science Offices, and Open Science Labs. An Open Science Office or Center might simply be a person or a small team with several paid hours a week devoted to organizing local activities for reproducible and open science practices. One example is the Open Science Office at the University of Mannheim, which includes an Open Science Officer and an Open Access Librarian (https://www.uni-mannheim.de/open-science/open-science-office/). Their activities include organizing open science days and workshops, offering grants for open science projects, and providing infrastructure.

Some German institutions, departments, and libraries have established larger Open Science Centers, where personnel promote and foster reproducible and open science practices by offering education and training (e.g., https://leibniz-psychology.org/) or forming networks and communities of researchers (e.g., https://www.uni-bielefeld.de/forschung/support/open-science-network/, https://www.osc.uni-muenchen.de/index.html, [57]. The QUEST Center at the Berlin Institute of Health and Charité Universitätsmedizin – Berlin provides services to support reproducible research practices in the institutional community, while also conducting meta-research and serving as a test incubator for interventions to improve research [58,59].

Open Science Labs may work on open science research projects, creating and providing software, and organizing book sprints and hackathons (e.g., https://www.tib.eu/en/research-development/research-groups-and-labs/open-science).

An alternative approach is to create or contribute to decentralized online resource centers. These online communities are often run by volunteers, and provide education and training on reproducible and open science practices. This may include curated databases of reproducible and open science-related resources, which are useful when setting up education and training programs. Several excellent online resource centers already exist, such as FORRT (https://forrt.org/) and the Open Scholarship Knowledge Base, which collaborates with the Center for Open Science (https://www.cos.io/communities/open-scholarship-knowledge-base).

Strategy 11 - Connect individuals and initiatives involved in reproducible research and open science practices: Our virtual brainstorming event highlighted the need for individuals and organizations to connect those working on similar topics, or in the same institution or region. There were several cases where attendees at the same institution, or in the same region, had never met. Many attendees felt isolated with their activities. Connections between groups can facilitate collaborations, provide opportunities for shared problem solving and mentorship, and allow different groups to support and amplify each other's efforts. Sharing materials and resources within collaborations might also lessen the workload for individuals. Collaborations allow groups to work across departments and fields, facilitating broader change within the institution. National reproducibility networks, like the GRN or UKRN [60], and their local nodes, or the Network of Open Science Initiatives (NOSI) [61] may provide infrastructure and serve as "connectors".

Tips

This section offers a few helpful tips for implementing each of the eleven strategies.

Offer Training

Tips for Strategy 1 - Offer reproducible research and open science courses

Select appropriate course formats and topics: When organizing a course or training event, select formats that align with your expertise, available resources, and the amount of time that you can invest. Investigators with expertise on a particular topic, for example, may offer single lectures or webinars, or collaborate with others to offer a course or webinar series.

Join training programs: Offering a reproducible research and open science course can be overwhelming for new instructors. Join multidisciplinary training programs, such as Reproducibility for Everyone (https://www.repro4everyone.org/), or participate in train-the-trainer programs, as for example offered by the Carpentries (https://carpentries.org/), to gain experience.

Participate in team teaching: Team teaching is especially valuable when training covers many topics or is intended for a multidisciplinary audience. Instructors may specialize in different topics (e.g., data management vs. reporting guidelines), fields, or study types (e.g., in vitro vs. preclinical vs. clinical biomedical research). Consider sharing course syllabi and materials as open access resources via repositories (e.g., Zenodo, Open Science Framework, PsychArchives) to help make reproducibility and open science courses the norm.

Offer training to different audiences: Consider offering training at many different levels (e.g., individual researchers, research groups, departments, institutions) and for individuals at different career stages. Partner with different organizations (e.g., institutional training, conference workshops, training offered by a scientific society or publishers) to extend your reach.

Include interdisciplinary perspectives: The concepts and skills discussed in reproducibility and open science training typically apply to many fields. Participants benefit from learning how problems manifest across fields, and exploring solutions from other fields that may be adapted to their own work.

Reuse available (online) resources and adapt materials where needed: Before creating new resources, consult available online resources, such as open lesson plans, presentations, videos, and interactive exercises (e.g., https://www.oercommons.org/ for resources). Materials for multidisciplinary audiences can often be adapted by selecting the topics most relevant to a specific field or replacing general examples with field-specific alternatives. Expertise and resources can also be shared among colleagues within a research institution via “lessons learned” or “best practices” discussions (https://journals.qucosa.de/ll/index).

Consider administrative and organizational aspects: Course organization involves more than selecting the format and delivering content. You may need to advertise the event, invite participants, set up a registration site, organize a venue, make technical arrangements, and send out reminders. Institutions can support course organizers by providing resources (see Strategy 10 below) or co-organizing larger courses.

Tips for Strategy 2 - Integrate reproducibility and open science skills into courses on other topics

Incorporate hands-on experience and real-life examples: Incorporate skills into practical or laboratory sessions to provide students with hands-on experience. This is especially valuable for undergraduate students who are not yet conducting their own research. Share examples of how a particular practice has enhanced or harmed research in the student's field to highlight the relevance of practices that you discuss.

Collaborate across the curriculum: Work with colleagues who teach subsequent courses to reinforce and build upon reproducible research and open science skills. Contact support staff (e.g., curriculum committee members or program coordinators) to integrate training opportunities throughout the curriculum (see also Strategy 6).

Tips for Strategy 3 - Provide hands-on training

Provide step-by-step instructions and feedback: This helps participants navigate early roadblocks, reducing barriers to implementation. Participants in hands-on courses also learn from each other's questions and experiences.

Consider team teaching: While practical experience often increases the student's motivation and confidence more than theoretical knowledge, teaching hands-on courses can be more challenging than giving straight lectures. Team teaching allows instructors to answer a broader range of questions, especially when participants come from different disciplines or have different study designs.

Clearly specify the intended audience in course advertisements: State the level of research and/or open science experience, the relevant fields or research designs, as well as the learning goals in the course announcement. This allows participants to select courses that teach skills relevant to their research.

Specify the anticipated workload and time commitment in course announcements: Explain any additional workload beyond the planned course time (e.g., preparatory tasks or homework) so that participants can plan accordingly.

Offer implementation options for different study phases: Address the different ways in which a skill might be implemented, depending on the phase of the participants' research project (e.g., study design, data collection, data analysis, manuscript preparation). For example, creating a data management plan is most useful in the study design phase [62], while research resource identifiers (https://scicrunch.org/resources) can be added at any time.

Set realistic expectations for implementation: Emphasize that few research groups have the time and resources to implement all reproducible research practices simultaneously and participants may not be able to implement all practices in their day-to-day research. The practice may not apply to the participant's research area or study phase, there may be obstacles to implementing the practice in the participant's research project, or the participant's advisors or co-authors may resist certain practices. Highlight the potential for "reverse mentoring", where participants can serve as mentors to their own supervisors on specific topics [63]. Prepare participants to address common concerns or barriers that may be raised by co-authors [24].

Tips for Strategy 4 - Conduct educational interventions for research groups

Group interventions may be very different depending on the context and the practice being implemented. While this strategy has great potential, it was one of the least common ones amongst event participants. More sharing of experiences on how to effectively implement this strategy is needed.

Ensure that the team leader is supportive: The work environment plays an important role in enabling teams to implement new practices, on both structural and social levels. Work with the team leader to address concerns and confirm their commitment to the proposed changes before starting the intervention.

Include everyone: Involve the whole research team when implementing new practices as this allows members to share expertise, identify common goals, and decide on reusable tools and procedures. Discuss concerns and barriers openly and transparently within the group.

Tips for Strategy 5 - Perform replication or meta-research studies as course projects

Consider the educational goals of the course, available resources, and student experience when designing a project: When conducting replication studies, for example, the project could focus on studies with open data and materials, or include studies with closed data and materials. Alternatively, instructors could contact the authors of studies to be replicated in advance to confirm that they can obtain data or support from the study authors (https://www.youtube.com/watch?v=NswZ6PqsHbU). Whereas replicating studies with open materials may reduce students' workload and reveal the advantages of open science, replicating studies without open materials teaches students about the importance of detailed methods. Students may also be involved in designing the project.

Carefully define the scope of the project: Participants should be able to complete the project with the time and resources available. Research projects can be predefined by course instructors or developed by participants in collaboration with the instructors. Project development is time-consuming and should be reserved for longer, more advanced courses [28].

Ensure that you have adequate support: Courses where participants work together to complete a single research project are uniquely challenging for instructors, who must balance the project demands with constraints imposed by the course duration. Having a student assistant, who provides administrative support while doing the research project alongside participants, reduces instructor burden while providing training for the supporting student.

Integrate reproducible research and open science practices: This might include preregistration, protocol sharing, open data, open code, posting preprints, using ORCIDs and CRediT authorship statements, or many other practices.

Focus on why: During class discussions, encourage participants to identify different approaches that they might use to handle a particular aspect of the project, compare the strengths and weaknesses of those approaches, and retrospectively reflect on the impact of the approaches that they decided upon. Understanding why the class selected a particular approach for a specific situation teaches participants to implement theoretical principles within the constraints imposed by an actual research study.

Use unanticipated challenges as opportunities to teach problem solving skills: Unanticipated challenges occur in every research project. They provide students with an opportunity to adapt and apply what they have learned by balancing theoretical principles with real-world constraints.

Create a positive and inclusive team dynamic: Ensuring that all team members are comfortable sharing ideas is essential for collaboration. Discuss strategies for good communication in multidisciplinary and multicultural teams. Encourage participants to get to know one another, work in small groups, and take advantage of leadership opportunities. We encourage readers to consult additional resources on these important topics.

Plan ahead if you aim to publish the study: Rigorous design is critical for publication. Establish transparent strategies for allowing the class to determine authorship order. Use CRediT (https://credit.niso.org/) and/or MeRIT [64] authorship statements to report participant contributions. Carefully explain each stage of the publication process for students who have limited experience with publishing. Stay in contact with participants until the manuscript is published.

Adapt Research Assessment Criteria and Program Requirements

Tips for Strategy 6 - Adjust curriculum to require reproducibility and open science training

Be persistent: Curriculum change is time consuming and requires top-down and bottom-up approaches, including support from institutional decision makers. Collaborate with administrators and curriculum committee members to add a new course to the curriculum or to make a course mandatory that was previously offered as an elective. If needed, repeat this process with committees from different departments and programs, adapting the course content to the program's needs.

Anticipate resistance: You may encounter resistance to adjusting the curriculum. Prepare responses to common concerns. Advocate for mandatory reproducibility and open science courses by using funding agency and journal mandates, information on the prevalence of these practices in the field, examples highlighting the problem of non-reproducible research within the field, course outlines, and student feedback from existing courses.

Seize opportunities: Stay in contact with administrators. While rare, the addition of new degree programs or restructuring of existing programs offers an excellent opportunity to require reproducible research and open science courses.

Tips for Strategy 7 - Require reproducible research and open science practices in undergraduate or graduate theses

Establish systems that encourage students to integrate reproducible research and open science practices early: Listing required practices (e.g., pre-registration of the thesis or thesis chapters, open code in form of a codebook or reproducible script, open materials) in the thesis agreement ensures that students are exposed to these concepts before starting their research. They can work with supervisors to develop plans to integrate reproducible and open-science-related practices from the beginning. Students gain hands-on experience with the challenges and benefits of applying these practices in their own work [65].

Form your own agreement: If your institution or department does not have requirements for reproducible research and open science practices in graduate theses, form your own individual agreement. List applicable practices and, if possible, describe how these will be part of the evaluation process. This can be initiated by the supervisor or by the supervised student.

Assess thesis requirements continuously: When adding new criteria, re-evaluate all degree requirements to ensure that they incentivize responsible research practices, are feasible, and can be completed in the expected timeframe. Reproducible and open science practices should be rewarded during thesis evaluation (e.g., by integrating them into the grading process), as they increase student workload.

Make additional materials available if possible: Including reproducible and open science practices into undergraduate and graduate theses leads to the generation of additional materials (e.g., thesis pre-registration, methods, data, and code). Consider depositing these outputs on public repositories alongside submitting these privately along with the thesis.

Tips for Strategy 8 - Include reproducible and open science practices in research(er) assessment

Consult existing resources and adapt where needed: A task force established by the Deutsche Gesellschaft für Psychology (German Psychological Society, DPG) works on overarching guidelines to incorporate reproducible and open science practices in hiring and promotion procedures in psychology [47,66–68]. The concrete suggestions provided may be adapted to selection processes in other scientific fields.

Provide assessment guidelines: Specify procedures for assessing and scoring open science indicators and reproducible research practices, and describe these procedures in materials for those being evaluated. Incorporate these procedures into an assessment guideline to share with hiring and evaluation committee members. This approach is currently implemented by the Berlin Institute of Health at Charité Universitätsmedizin - Berlin (https://www.bihealth.org/en/notices/wt-bih-merit, [44,69].

Involve non-committee members in the process: Support committee members in applying responsible research indicators by including a non-voting member who is an expert in evaluating reproducible research and open science practices, as is done by the Berlin Institute of Health and Charité. Further, include ECRs in the discussion about research assessment, as their perspectives can be helpful in adapting current criteria to incentivize responsible practices. ECRs often champion these efforts and some have specialized training in new approaches and tools for reproducible research and open science.

Allow for a transition period: When adjusting research(er) assessment, notify all stakeholders involved in advance and allow for a transition period. This helps to avoid placing those (early career) researchers at a disadvantage who were originally working under different assessment guidelines.

Build Communities

Tips for Strategy 9 - Organize journal clubs and other community-learning opportunities

Foster accessible discussions: Making discussions accessible to everyone can be challenging, as some participants may have extensive knowledge of reproducibility and open science topics, whereas others may have no prior experience. This can lead to attrition. Consider running “beginner” and “advanced” community meetings or assigning more experienced mentors to beginners. Provide a list of key publications or resources already discussed in previous sessions (e.g.,[70]. Assign different roles to individuals in the meetings and discussions depending on their interests and expertise (e.g., discussion facilitator, meeting organizer, presenter introducing the topic of the meeting to the community, critic).

Build communities: Organize regular meetings to make it easy for participants to engage with others who are interested in reproducible and open science practices. Informal formats, such as open science lunches, can be useful here. Depending on expertise, use hacky hours or other formats to create a community around open code, tools, and new techniques, and discuss practical considerations for implementing these techniques. Materials such as the Open Science Community Starter Kit from the International Network of Open Science/Scholarship Communities can help you get started (https://www.startyourosc.com/).

Share information and resources: Keeping your community members informed and attracting new participants are challenging, but important, tasks. Consider using different formats (e.g., talks, workshops, position papers) and platforms (e.g., online discussion forums, wikis, repositories) to engage with others while sharing materials and updates.

Adjust the frequency of meetings to meet your community's needs: If meetings take place too often, attendance may decrease. Clarifying which frequency works for the community (e.g., once per term) helps to ensure attendance and efficient time use.

Tips for Strategy 10 - Create resource hubs:

Start with an attainable goal: Resource hubs range from small teams to centers with extensive resources and infrastructure. Before planning and setting up a resource hub, identify institutional or administrative support and consider the resources available to you. Starting with a smaller hub or team allows you to gain experience, build momentum, and refine your approach and activities. Once the hub is established, you can amplify your efforts and expand.

Identify allies and collaborators: Contact individuals, offices, or centers who are organizing activities that you would like to establish in your research hub environment. Build a network of collaborators who can support you in creating or amplifying a resource hub. In addition, seek out the support of institutional leadership and administrative staff. These are important allies when creating new resource hubs.

Consider funding and sustainability: The amount and source of funding, as well as any conditions for renewal, will influence the scope and priorities of the hub. Short-term funding may require staff to focus on rapidly achievable goals that add value to the community, whereas longer-term funding may allow staff to address more complex topics.

Tips for Strategy 11 - Connect individuals and initiatives involved in reproducible research and open science practices

Seek out networking opportunities: Participate in networking events, such as our virtual brainstorming event, to identify others that share your interests regarding reproducible and open science training, learn from each other, and join ongoing activities. Alternatively, organize an event yourself.

Identify external support: To achieve your goals, you may need expertise that is not available locally. Use living “speaker directory” documents to identify speakers, collaborators, or others with relevant expertise (e.g., https://www.ukrn.org/speaker-directory/).

Connect with supporters to obtain feedback: Identify and communicate with individuals who are not actively involved in reproducible research and open science, but who support these practices and can give constructive feedback. Feedback can help you to assess the feasibility of proposed practices, while identifying and addressing barriers to implementation.

Consult experts when necessary: Sometimes issues arise that require specific expertise (e.g. seeking legal advice when dealing with intellectual property issues). Consult appropriate experts or departments to reduce risk and facilitate the implementation.

Limitations

Several limitations of the present work and the virtual brainstorming event have to be considered. All participants were working in Germany. Many of them worked in psychology or the biomedical sciences. The strategies shared may not be generalizable to other fields or countries. Integrating additional fields into the discussion is important to facilitate systemic change that meets the needs of departments throughout the institution. Further, most participants were working on grassroots activities. Crucial infrastructure personnel, such as librarians or software engineers, were underrepresented. Exploration of top-down strategies for making reproducible research and open science training the norm is needed. This will require other stakeholders, particularly those in leadership or administrative positions. While this paper offers tips and lessons learned based on participants' experiences, it is not a qualitative research study. Studies examining whether the practices discussed increase the proportion of research that implements reproducible research and open science practices are needed. The proposed approaches may not be feasible for all institutions, departments, or research fields, or may need to be adapted to meet local needs.

Conclusions

The eleven strategies discussed here highlight that there are several actions that can be taken to make reproducible research and open science training the norm at research institutions, beyond offering courses and workshops on these topics. These strategies can be grouped into three main areas: (1) offering training, (2) adapting research assessment criteria and program requirements, and (3) building communities. Researchers can take action in their roles as scientists, supervisors, mentors, instructors, and members of curriculum design or hiring and evaluation committees. Combining these bottom-up activities with top-down efforts by institutional leadership and research support staff, including librarians, information technology professionals, and members of administrative committees, could accelerate institutional implementation of reproducible research and open science practices across disciplines. Sharing expertise among institutions may also be beneficial. Making reproducible research and open science training the norm will require a broad coalition, and we hope that this piece will inspire others to join these efforts.

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References

1. Errington TM, Denis A, Perfito N, Iorns E, Nosek BA. Challenges for assessing replicability in preclinical cancer biology. eLife. 2021;10: e67995. doi:10.7554/eLife.67995

2. Vazire S. Implications of the Credibility Revolution for Productivity, Creativity, and Progress. Perspect Psychol Sci. 2018;13: 411–417. doi:10.1177/1745691617751884

3. Baker M. 1,500 scientists lift the lid on reproducibility. Nature. 2016;533: 452–454. doi:10.1038/533452a

4. Ioannidis JPA, Greenland S, Hlatky MA, Khoury MJ, Macleod MR, Moher D, et al. Increasing value and reducing waste in research design, conduct, and analysis. The Lancet. 2014;383: 166–175. doi:10.1016/S0140-6736(13)62227-8

5. Chan A-W, Song F, Vickers A, Jefferson T, Dickersin K, Gøtzsche PC, et al. Increasing value and reducing waste: addressing inaccessible research. The Lancet. 2014;383: 257–266. doi:10.1016/S0140-6736(13)62296-5

6. Downs RR. Improving Opportunities for New Value of Open Data: Assessing and Certifying Research Data Repositories. Data Sci J. 2021;20: 1. doi:10.5334/dsj-2021-001

7. Diaba-Nuhoho P, Amponsah-Offeh M. Reproducibility and research integrity: the role of scientists and institutions. BMC Res Notes. 2021;14: 451. doi:10.1186/s13104-021-05875-3

8. Barba LA. Terminologies for Reproducible Research. 2018 [cited 2 Jan 2023]. doi:10.48550/ARXIV.1802.03311

9. Claerbout JF, Karrenbach M. Electronic documents give reproducible research a new meaning. SEG Technical Program Expanded Abstracts 1992. Society of Exploration Geophysicists; 1992. pp. 601–604. doi:10.1190/1.1822162

10. Parsons, S., Azevedo, F., Elsherif, M.M., Guay, S., Shahim, O.N., Govaart, G.H., et al. A community-sourced glossary of open scholarship terms. Nat Hum Behav. 2022;6: 312–318. doi:10.1038/s41562-021-01269-4

11. Nosek BA, Hardwicke TE, Moshontz H, Allard A, Corker KS, Dreber A, et al. Replicability, Robustness, and Reproducibility in Psychological Science. Annu Rev Psychol. 2022;73: 719–748. doi:10.1146/annurev-psych-020821-114157

12. Wolf C. Implementing Open Science: The GESIS Perspective; Talk given at Institute Day of GESIS, 28 September 2017. GESIS Pap. 2017 [cited 16 May 2023]. doi:10.21241/SSOAR.54950

13. Page MJ, Moher D. Evaluations of the uptake and impact of the Preferred Reporting Items for Systematic reviews and Meta-Analyses (PRISMA) Statement and extensions: a scoping review. Syst Rev. 2017;6: 263. doi:10.1186/s13643-017-0663-8

14. Blanco D, Altman D, Moher D, Boutron I, Kirkham JJ, Cobo E. Scoping review on interventions to improve adherence to reporting guidelines in health research. BMJ Open. 2019;9: e026589. doi:10.1136/bmjopen-2018-026589

15. Grant SP, Mayo-Wilson E, Melendez-Torres GJ, Montgomery P. Reporting Quality of Social and Psychological Intervention Trials: A Systematic Review of Reporting Guidelines and Trial Publications. Gagnier JJ, editor. PLoS ONE. 2013;8: e65442. doi:10.1371/journal.pone.0065442

16. Hardwicke TE, Thibault RT, Kosie JE, Wallach JD, Kidwell MC, Ioannidis JPA. Estimating the Prevalence of Transparency and Reproducibility-Related Research Practices in Psychology (2014–2017). Perspect Psychol Sci. 2022;17: 239–251. doi:10.1177/1745691620979806

17. Hardwicke TE, Wallach JD, Kidwell MC, Bendixen T, Crüwell S, Ioannidis JPA. An empirical assessment of transparency and reproducibility-related research practices in the social sciences (2014–2017). R Soc Open Sci. 2020;7: 190806. doi:10.1098/rsos.190806

18. Morais, Rita, Saenen, Bregt, Garbuglia, Federica, Berghmans, Stephane, Gaillard, Vinciane. From principles to practices: Open Science at Europe's universities. 2020-2021 EUA Open Science Survey results. Zenodo; 2021 Jul. doi:10.5281/ZENODO.5062982

19. UNESCO. UNESCO Recommendation on Open Science. UNESCO; 2021. doi:10.54677/MNMH8546

20. Holman C, Kent BA, Weissgerber TL. How to connect academics around the globe by organizing an asynchronous virtual unconference. Wellcome Open Res. 2021;6: 156. doi:10.12688/wellcomeopenres.16893.2

21. Grüning DJ, Frank M. Open Science events: A best practice overview. PsyArXiv; 2023 Jan. doi:10.31234/osf.io/vjp5w

22. Boyle, Neasa, Centeno, Eduarda, Dierkes, Jens, Heyard, Rachel, Kao, Joyce, Lakshminarayanan, Harini, et al. Open Science: Principles and Practices. Zenodo; 2023 Apr. doi:10.5281/ZENODO.7818767

23. Rohmann J, Wülk N, Piccininni M, Grillmaier H, Abdikarim I, Kurth T, et al. Peerspectives: peer review training initiative for the biomedical sciences. 2022 [cited 16 May 2023]. doi:10.17605/OSF.IO/WYEGC

24. Heise V, Holman C, Lo H, Lyras EM, Adkins MC, Aquino MRJ, et al. Ten simple rules for implementing open and reproducible research practices after attending a training course. Markel S, editor. PLOS Comput Biol. 2023;19: e1010750. doi:10.1371/journal.pcbi.1010750

25. Lowndes JSS, Froehlich HE, Horst A, Jayasundara N, Pinsky ML, Stier AC, et al. Supercharge your research: a ten-week plan for open data science. Nature. 2019; d41586-019-03335–4. doi:10.1038/d41586-019-03335-4

26. Seibold H, Czerny S, Decke S, Dieterle R, Eder T, Fohr S, et al. A computational reproducibility study of PLOS ONE articles featuring longitudinal data analyses. Wicherts JM, editor. PLOS ONE. 2021;16: e0251194. doi:10.1371/journal.pone.0251194

27. Reedy M, Mellor DT, Höffler JH, Bauer G, Gereke J, Soiné H, et al. Workshop: Teaching Replication in the Social Sciences. 2021 [cited 16 May 2023]. Available: https://osf.io/5sgf7/

28. Weissgerber TL. Training early career researchers to use meta-research to improve science: A participant-guided “learn by doing” approach. PLOS Biol. 2021;19: e3001073. doi:10.1371/journal.pbio.3001073

29. Neuendorf C, Kocaj A, Rüdiger C, Jansen M. Thematisierung von Replikationen und Open Science Praktiken in Lehre und Studium – Die Rolle von Sekundärdatenanalysen. Psychol Rundsch. 2022;73: 44–45. doi:10.1026/0033-3042/a000575

30. Kroon C, Breuer L, Jones L, An J, Akan A, Mohamed Ali EA, et al. Blind spots on western blots: Assessment of common problems in western blot figures and methods reporting with recommendations to improve them. Bertrand MJM, editor. PLOS Biol. 2022;20: e3001783. doi:10.1371/journal.pbio.3001783

31. Jambor H, Antonietti A, Alicea B, Audisio TL, Auer S, Bhardwaj V, et al. Creating clear and informative image-based figures for scientific publications. Swedlow JR, editor. PLOS Biol. 2021;19: e3001161. doi:10.1371/journal.pbio.3001161

32. Jekel M, Fiedler S, Allstadt Torras R, Mischkowski D, Dorrough AR, Glöckner A. How to Teach Open Science Principles in the Undergraduate Curriculum—The Hagen Cumulative Science Project. Psychol Learn Teach. 2020;19: 91–106. doi:10.1177/1475725719868149

33. Button K. Reboot undergraduate courses for reproducibility. Nature. 2018;561: 287–287. doi:10.1038/d41586-018-06692-8

34. Button KS, Chambers CD, Lawrence N, Munafò MR. Grassroots Training for Reproducible Science: A Consortium-Based Approach to the Empirical Dissertation. Psychol Learn Teach. 2020;19: 77–90. doi:10.1177/1475725719857659

35. Schönbrodt F, Heene M, Zehetleitner M, Maier M, Scheel AM, Zygar-Hoffmann C, et al. Open Science Initiative in Psychology @LMU. 2015 [cited 16 May 2023]. Available: https://osf.io/mgwk8/

36. Schönbrodt F, Zygar-Hoffmann C, Frank M, Gollwitzer M. Gute wissenschaftliche Praxis „hands-on“: Ein Kerncurriculum für Empirische Praktika. Psychol Rundsch. 2022;73: 130–132. doi:10.1026/0033-3042/a000590

37. Abele-Brehm AE, Bühner M. Wer soll die Professur bekommen?: Eine Untersuchung zur Bewertung von Auswahlkriterien in Berufungsverfahren der Psychologie. Psychol Rundsch. 2016;67: 250–261. doi:10.1026/0033-3042/a000335

38. Allen C, Mehler DMA. Open science challenges, benefits and tips in early career and beyond. PLOS Biol. 2019;17: e3000246. doi:10.1371/journal.pbio.3000246

39. Smaldino PE, McElreath R. The natural selection of bad science. R Soc Open Sci. 2016;3: 160384. doi:10.1098/rsos.160384

40. European Commission. Directorate General for Research and Innovation. Towards a reform of the research assessment system: scoping report. LU: Publications Office; 2021. Available: https://data.europa.eu/doi/10.2777/707440

41. Pontika N, Gyawali B, Corriea A, Brinken H, Pride D, Cancellieri M, et al. How do career promotion policies affect research publications and open access? Open Res Eur. 2022;2: 99. doi:10.12688/openreseurope.14921.1

42. Schönbrodt F. Training students for the Open Science future. Nat Hum Behav. 2019;3: 1031–1031. doi:10.1038/s41562-019-0726-z

43. Kip, Miriam, Dirnagl, Ulrich. Die MERIT App. Wissenschaftsleistungen in Berufungsverfahren - digital aufbereitet. Forsch Lehre. 2021;28: S824–S825.

44. Kip M, Dirnagl U, Koenig S, Wiebach J, Dunkel M, Mallach M. MERIT App Charité. 2022 [cited 16 May 2023]. Available: https://osf.io/p2vyw/

45. Schönbrodt F, Schramm LFF, Etzel FT, Bergmann C, Mellor DT, Schettino A, et al. Academic job offers that mentioned open science. 2018 [cited 16 May 2023]. doi:10.17605/OSF.IO/7JBNT

46. Schönbrot F. Changing hiring practices towards research transparency: The first open science statement in a professorship advertisement – nicebread.de. 6 Jan 2016 [cited 16 May 2023]. Available: https://www.nicebread.de/open-science-hiring-practices/

47. Gärtner A, Leising D, Schönbrodt FD. Responsible Research Assessment II: A specific proposal for hiring and promotion in psychology. PsyArXiv; 2022 Nov. doi:10.31234/osf.io/5yexm

48. Gärtner A, Leising D, Schönbrodt FD. Responsible Research Assessment II: A specific proposal for hiring and promotion in psychology. PsyArXiv; 2022 Nov. doi:10.31234/osf.io/5yexm

49. Gierend K, Wodke JAH, Genehr S, Gött R, Henkel R, Krüger F, et al. TAPP: Defining standard provenance information for clinical research data and workflows - Obstacles and opportunities. Companion Proceedings of the ACM Web Conference 2023. Austin TX USA: ACM; 2023. pp. 1551–1554. doi:10.1145/3543873.3587562

50. Orben A, Parsons S, Crüwell S, Pickering J, Drax K, Jaquiery M. ReproducibiliTea. 2018 [cited 16 May 2023]. Available: https://osf.io/3qrj6/

51. Orben A. A journal club to fix science. Nature. 2019;573: 465–465. doi:10.1038/d41586-019-02842-8

52. Armeni K, Brinkman L, Carlsson R, Eerland A, Fijten R, Fondberg R, et al. Towards wide-scale adoption of open science practices: The role of open science communities. Sci Public Policy. 2021;48: 605–611. doi:10.1093/scipol/scab039

53. Azevedo F, Liu M, Pennington CR, Pownall M, Evans TR, Parsons S, et al. Towards a culture of open scholarship: the role of pedagogical communities. BMC Res Notes. 2022;15: 75. doi:10.1186/s13104-022-05944-1

54. Pownall M, Azevedo F, Aldoh A, Elsherif M, Vasilev M, Pennington CR, et al. Embedding open and reproducible science into teaching: A bank of lesson plans and resources. Scholarsh Teach Learn Psychol. 2021 [cited 16 May 2023]. doi:10.1037/stl0000307

55. Elsherif MM, Middleton SL, Phan JM, Azevedo F, Iley BJ, Grose-Hodge M, et al. Bridging Neurodiversity and Open Scholarship: How Shared Values Can Guide Best Practices for Research Integrity, Social Justice, and Principled Education. MetaArXiv; 2022 Jun. doi:10.31222/osf.io/k7a9p

56. Pownall M, Azevedo F, König LM, Slack HR, Evans TR, Flack Z, et al. Teaching Open and Reproducible Scholarship: A Critical Review of the Evidence Base for Current

Pedagogical Methods and their Outcomes. MetaArXiv; 2022 Apr. doi:10.31222/osf.io/9e526

57. Hachmeister N, Schirrwagen J. Open Science Whitepaper – Universität Bielefeld. 2021; 3738750 bytes. doi:10.4119/UNIBI/2956951

58. Strech D, Weissgerber T, Dirnagl U, on behalf of QUEST Group. Improving the trustworthiness, usefulness, and ethics of biomedical research through an innovative and comprehensive institutional initiative. PLOS Biol. 2020;18: e3000576. doi:10.1371/journal.pbio.3000576

59. Drude N, Martinez-Gamboa L, Haven T, Holman C, Holst M, Kniffert S, et al. Finding the best fit for improving reproducibility: reflections from the QUEST Center for Responsible Research. BMC Res Notes. 2022;15: 270. doi:10.1186/s13104-022-06108-x

60. UK Reproducibility Network Steering Committee. From grassroots to global: A blueprint for building a reproducibility network. PLOS Biol. 2021;19: e3001461. doi:10.1371/journal.pbio.3001461

61. Schönbrodt F, Baumert A, Glöckner A, Back M, Arslan RC, Voracek M, et al. Netzwerk der Open-Science-Initiativen (NOSI). 2016 [cited 16 May 2023]. doi:10.17605/OSF.IO/TBKZH

62. Michener WK. Ten Simple Rules for Creating a Good Data Management Plan. Bourne PE, editor. PLOS Comput Biol. 2015;11: e1004525. doi:10.1371/journal.pcbi.1004525

63. Pizzolato D, Dierickx K. Reverse mentoring to enhance research integrity climate. BMC Res Notes. 2022;15: 209. doi:10.1186/s13104-022-06098-w

64. Nakagawa S, Ivimey-Cook ER, Grainger MJ, O'Dea RE, Burke S, Drobniak SM, et al. Method Reporting with Initials for Transparency (MeRIT) promotes more granularity and accountability for author contributions. Nat Commun. 2023;14: 1788. doi:10.1038/s41467-023-37039-1

65. Kathawalla U-K, Silverstein P, Syed M. Easing Into Open Science: A Guide for Graduate Students and Their Advisors. Collabra Psychol. 2021;7: 18684. doi:10.1525/collabra.18684

66. Leising D, Schönbrodt F, Gärtner A. Responsible Research Assessment: Implementing DORA for hiring and promotion in psychology. 2022 [cited 16 May 2023]. doi:10.17605/OSF.IO/4WYNR

67. Schönbrodt FD, Gärtner A, Frank M, Gollwitzer M, Ihle M, Mischkowski D, et al. Responsible Research Assessment I: Implementing DORA for hiring and promotion in psychology. PsyArXiv; 2022 Nov. doi:10.31234/osf.io/rgh5b

68. Gärtner A, Leising D, Schönbrodt FD. Empfehlungen zur Bewertung wissenschaftlicher Leistungen bei Berufungsverfahren in der Psychologie. PsyArXiv; 2023 Mar. doi:10.31234/osf.io/3yjz7

69. Kip M, Koenig S, Dirnagl U. Mechanisms of robust, innovative and translational research (MERIT). 2022 [cited 16 May 2023]. doi:10.17605/OSF.IO/ZMUHW

70. Wessolowski N, Fricke K, Herrmann A, Wendt M, Tigges D, Niemann M, et al. Open Science Workgroup, Medical School Hamburg. 2021 [cited 16 May 2023]. doi:10.17605/OSF.IO/5SEZD

Supporting Information - Event Format

S1 Text for **Eleven Strategies for Making Reproducible Research and Open Science Training the Norm at Research Institutions**

Methodological details for the virtual brainstorming event

The organizers (SA, ABB, SF, TH, VH, CH, TLW) invited participants to attend the brainstorming event “Making reproducibility and open science education and training the norm” in March 2022. Participants were invited by contacting nodes of the German Reproducibility Network, and disseminating information through mailing lists and organizations focused on reproducible research and open science training in Germany. The virtual brainstorming consisted of (1) a virtual networking event prior to the brainstorm, (2) an asynchronous virtual brainstorming using an online discussion board, and (3) small, live group discussions in virtual meetings on various topics related to making reproducible research and open science education and training the norm. The format, on which this event was based, has been described in detail previously [20].

The brainstorming event included the organizers and 96 active participants over two days. The organizers used guiding questions to structure the asynchronous discussion:

1. What resources and strategies are already being used to train researchers in reproducibility and open science in Germany?

2. What opportunities and creative solutions exist to expand and improve reproducibility education in Germany?

3. How can we make reproducibility education/training the norm in Germany? What top-down and bottom-up approaches can we use? What are the barriers we face and how can we overcome them to make reproducibility education and training the norm?

Discussions included small group conversations in virtual meetings and asynchronous written conversations on the online platform Slack. Event organizers later synthesized these discussions into the eleven strategies and tips presented in this paper. No formal methodological procedure was used to formulate the outlined strategies.

An outline and several draft versions were shared with event participants to get their feedback and the manuscript was adjusted accordingly. Participants who provided input to the outline and manuscript draft were included as co-authors.