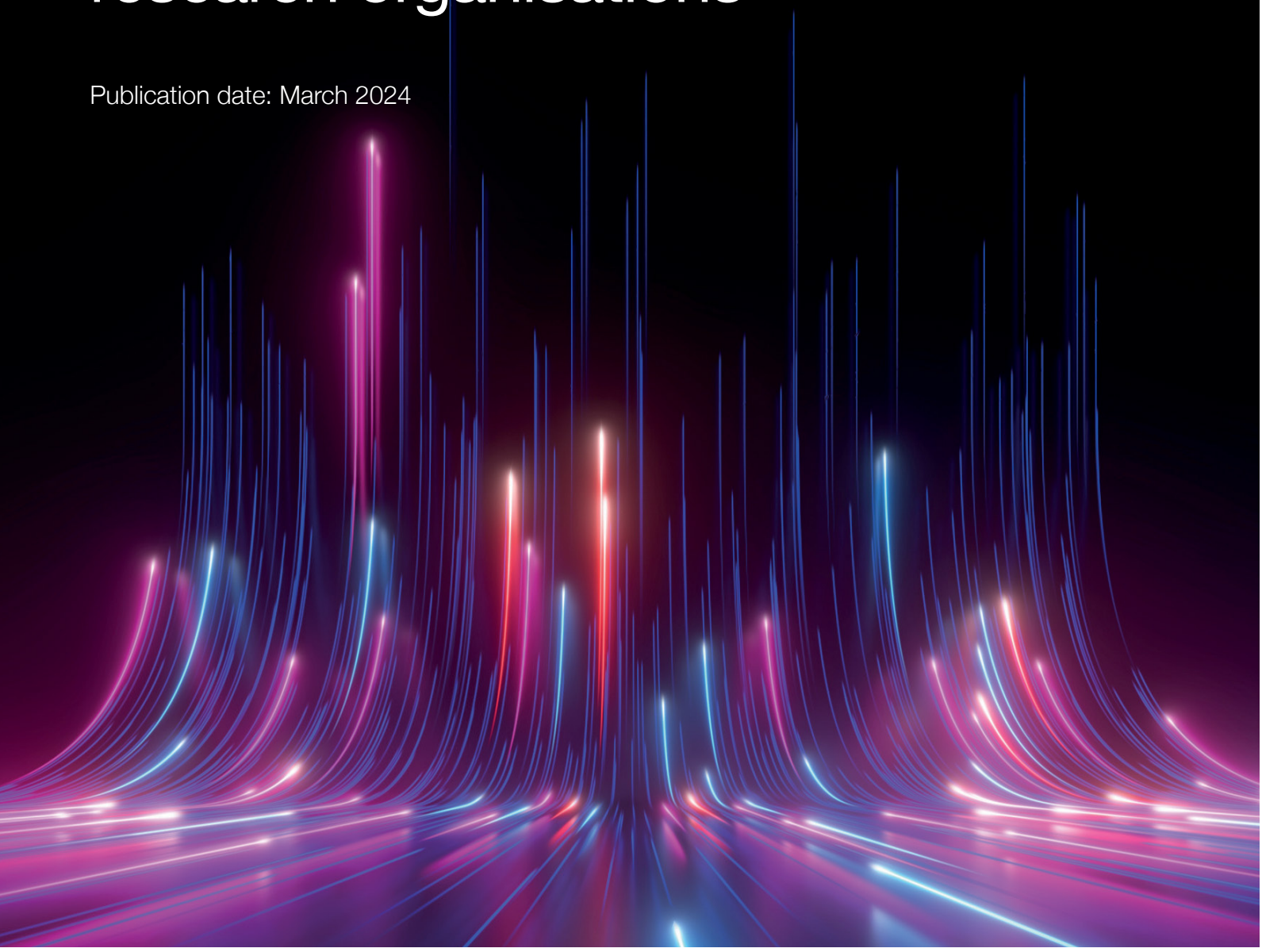
Knowledge Exchange

Approaches to scaling up reproducibility in research organisations

Publication date: March 2024



Approaches to scaling up reproducibility in research organisations

Authored by: Michelle Barker (https://orcid.org/0000-0002-3623-172X) and Neil Chue Hong (https://orcid.org/0000-0002-8876-7606)

Email: **office@knowledge-exchange.info**

DOI: **10.5281/zenodo.10663903**

This study has been commissioned by Knowledge Exchange (KE), a group of national organisations from six European countries supporting research infrastructure and services to enable the use of digital technologies to improve higher education and research: CSC in Finland, CNRS in France, DeiC in Denmark, DFG in Germany, Jisc in the UK and SURF in the Netherlands.

Acknowledgements

This study was underpinned by the work of the KE Task and Finish Group “Fair data and software supporting reproducibility”; who were instrumental in scoping the study, providing feedback and reviewing the results.

The group was led by Anna Mette Morthorst and Jean-Francois Nominé as KE Group leads and Laurents Sesink and Karsten Kryger Hansen as expert leads:

- Anna Mette Morthorst (Danish e-infrastructure cooperation (DeiC)
  https://orcid.org/0000-0001-5670-2464
- Birgit Schmidt (University of Göttingen)
  https://orcid.org/0000-0001-8036-5859
- Birte Christensen-Dalsgaard (Aarhus University)
  https://orcid.org/0000-0002-7172-6875
- Daniel Roewenstrunk (University of Paderborn)
  https://orcid.org/0000-0001-6271-2095
- Egon Heuson (Centrale Lille)
  https://orcid.org/0000-0001-6904-9214
- Jean-Francois Nominé (The French National Centre for Scientific Research (CNRS)
  https://orcid.org/0000-0003-1526-7608
- Karsten Kryger Hansen (Aalborg University Library)
  https://orcid.org/0000-0002-2407-8764
- Laurents Sesink (SURF)
  https://orcid.org/0000-0001-7880-5413
- Leo Lahti (University of Turku)
  https://orcid.org/0000-0001-5537-637X
- Loek Brinkman, (Data Archiving and Networked Services (DANS)
  https://orcid.org/0000-0003-3997-1173
- Matt Jaquiery (University of Oxford)
  https://orcid.org/0000-0003-3599-1580
- Olivier Rouchon (The French National Centre for Scientific Research (CNRS)
  https://orcid.org/0000-0002-1816-5546
- Stefanie Mewes (Deutsche Forschungsgemeinschaft (DFG)

- Toumas Alatera (Tampere University)
  https://orcid.org/0000-0002-3448-3448

We also gratefully acknowledge the support from Bas Cordewener, Priscilla Dibble and Sarah James (Knowledge Exchange Office); and Anders Conrad, Paula Martinez Lavanchy, Etienne Roesch and Marta Teperek. Finally, we record our appreciation to the study participants for their valuable insights and for their time, without which this study would not have been possible.

Contents

Executive summary

Reproducibility is recognised as a critical aim of modern research and is a part of major research reform agendas such as open science. It is a critical factor in both ensuring the quality and integrity of research, and accelerating discovery. However, the diversity of digital research processes and outputs, including research data and software, create challenges to the creation of reproducible research outcomes. There are also a range of stakeholders in the international research ecosystem who have different roles to play in supporting and incentivising reproducibility, including researchers and research-adjacent support staff, funders, policy makers, publishers, and institutional managers.

This report identifies how reproducibility can be scaled up at research organisations. It was commissioned by Knowledge Exchange, following previous work on open science, to investigate how the practice of conducting research in a reproducible way can be scaled up from pioneers to the majority of researchers and research-adjacent support staff. The report focuses on meso-level factors, such as groups, organisations and communities, rather than micro- or macro-level factors (as defined in the Knowledge Exchange Open Science Framework), to understand the role of research organisations and the people within them (who both undertake and support research). The findings in this report are the result of a mixed methods approach study, which combined a literature review, survey, interviews and focus groups.

The major output of this work is a framework for sustainable solutions for a wider uptake of reproducible research practices. It should be noted that this framework is focused on how well organised an organisation is at scaling up reproducibility practices, not the maturity of reproducibility practices and how well they adhere to what is commonly understood to be best practice.

The framework consists of three parts:

1. **Organisational levels:** These are levels that an organisation may progress through in its scaling up of reproducibility, and are focused on internal aspects of the organisation.

2. **Enablers of scaling up reproducibility:** Seven major types of enablers (based on the taxonomy by Davidson et al. (2022) support or catalyse the transition from one level to another, through a variety

understanding approaches to scaling up reproducibility in research institutions. The framework can be used by a range of internal stakeholders with differing goals, such as institutional leaders seeking to align organisational strategies, or managers wishing to provide the support that staff in their part of the organisation may be seeking. The intention is also to enable dialogue between managers and researchers to create collaborative and

of interventions:

- Tools
- Education and training in research reproducibility
- Incentives to enhance awareness, accessibility and understanding
- Modelling and mentoring to encourage research reproducibility

- Review and feedback
- Expert involvement and advice
- Policies and procedures

3. **Assessment worksheet:** This allows an organisation to assess its capability to support reproducibility practices, and act as a starting point for discussions around maintaining or improving this capability. It is complemented by guidelines for usage.

This report does not provide direct recommendations to the reader, as there is no single set of interventions that work at all types of organisation. Instead, it should be used to enable research organisations to engage with those involved in reproducibility to help share and extend good practice. An infographic aimed at key stakeholders has also been produced to make it easier to disseminate the outcomes of this study. It will be stakeholders. A useful next stage would now be for the community to engage with the framework, to enable testing and evaluation to increase its value. This could also provide better understanding of the importance of community in transitioning between levels; however, the reality of the status of reproducibility is highly varied not only across the research ecosystem internationally, but also across research organisations, and even within organisations, faculties and teams. The ongoing work of both national reproducibility networks and coordination across these provide one avenue for possibly supporting this, with university consortia providing another.

The Knowledge Exchange (KE) partners are six key national organisations within Europe tasked with developing infrastructure and services to enable the use of digital technologies to improve

important to ensure that the majority of researchers are provided with appropriate enablers and interventions, if culture change around reproducibility is to be achieved.

A shorter version of the framework, including guidance and worksheet, is also available as a separate document (10.5281/zenodo.10664660) for use by

Science (CSC) in Finland, National Centre for Scientific Research (CNRS) in France, Danish e-Infrastructure Consortium (DeiC) in Denmark, German Research Foundation (DFG) in Germany, Jisc in the UK, and SURF in the Netherlands.

1. Introduction

Reproducibility is a critical factor in ensuring the quality and integrity of research, as improving the **reliability and efæiency of scientiæ research can increase the credibility of the published scientiæ** literature and accelerate discovery and foster innovation to increase research and social outcomes. However, reproducibility has become increasingly complex as research has become inherently computational, involving an extraordinarily rich and diverse set of digital processes and outputs, including research data and software. For many, the digital parts of research are treated differently from more traditional elements, reducing the ability to create reproducible research outcomes. A wide variety of stakeholders have roles to play in improving this, and whilst there have been many advances on how to support reproducibility, challenges also remain.

This report identifies how reproducibility can be scaled up at research institutions. After the introduction, the second section of this report provides relevant frameworks and the rationale for the study's focus on the meso-level (as defined in the Knowledge Exchange Open Science Framework) to increase research reproducibility within institutions. The third section explains the mixed methods approach utilised and the demographics of participants, and initial analysis. Section four uses this analysis to provide a framework for understanding approaches to scaling up reproducibility in research institutions. The framework can be used by a range of internal stakeholders with differing goals, such as institutional leaders seeking to align organisational strategies, and managers wishing to provide the support that staff in their part of the organisation may be seeking. The intention is also to enable dialogue between managers and researchers to create collaborative and sustainable solutions for a wider uptake of reproducible research practices. It should be noted that this framework is focused on how well organised an organisation is at scaling up reproducibility practices (i.e., access and coordination), not the maturity of reproducibility practices and how well they adhere to what is commonly understood to be best practice in reproducibility.

While this work has focussed on computational reproducibility, the framework developed could be used to assess the way an organisation approaches non-computational reproducibility. Likewise, the study may provide insight into other aspects of open research/ open science, as it itself draws on a wider range of reproducibility-adjacent sources, including digital preservation (Digital Preservation Coalition, 2021) and research quality (Davidson et al., 2022), Ultimately, the outcomes of this study do not stand alone, but are expected to be used by wider communities of practice, such as national reproducibility networks, to embed the practice of research reproducibility at all levels. to disseminate the outcomes of this study. It will be important to ensure that the majority of researchers are provided with appropriate enablers and interventions, if culture change around reproducibility is to be achieved.

This work was conducted by Dr Michelle Barker and Professor Neil Chue Hong on behalf of the Knowledge Exchange, to expand Knowledge Exchange leadership on aspects of open science to investigate how the practice of conducting research in a reproducible way can be scaled up from pioneers to the majority of researchers and research support staff. The Knowledge Exchange Task and Finish Group focused on reproducibility oversaw this activity, as described in the Acknowledgements. The Knowledge Exchange partners are six key national organisations within Europe tasked with developing infrastructure and services to enable the use of digital technologies to improve higher education and research: IT Center for Science (CSC) in Finland, National Centre for Scientific Research (CNRS) in France, Danish e-Infrastructure Consortium (DeiC) in Denmark, German Research Foundation (DFG) in Germany, Jisc in the UK, and SURF in the Netherlands.

This study defines reproducibility as "the ability of researchers, other than the original researchers, to achieve the same findings using the same data and analysis" (Claerbout & Karrenbach, 1992). However, it should be noted that some participants focused on open science and/or replicability rather than reproducibility; in some cases with understanding of the differences but choosing a different focus due to the large overlap of these areas with reproducibility, and in some cases using the terms interchangeably.

This report does not provide direct recommendations to the reader, as there is no single set of interventions that work at all types of organisation. Instead, it should be used to enable research organisations to engage with those involved in reproducibility to help share and extend good practice. An infographic aimed at key stakeholders has also been produced to make it easier

2. Increasing research reproducibility through a meso-level focus

The reproducibility of research is widely accepted as an ambition that will enhance the quality and condition of research. Reproducing research and repeating analyses can conæm the veracity of the original results which can therefore more reliably be built upon, stimulating and accelerating research. However, conducting and managing research in such a way that it is reproducible is a complex challenge (Knowledge Exchange, 2022a).

In 2020, the Knowledge Exchange agreed on the scoping of an activity to contribute to the development of beneficial reproducible research practices (Knowledge Exchange, 2022b), building on previous work by the Knowledge Exchange that investigated the complex environment of stakeholders in which reproducible research takes place (Chiarelli et al., 2021; European Commission Directorate General for Research and Innovation et al., 2022). Reproducibility is recognised as a critical aim of modern research and is a part of major research reform agendas such as open science. Improving the reliability and efficiency of scientific research will increase the credibility of the published scientific literature and accelerate discovery (Munafò et al., 2017) and can foster innovation to increase research and social outcomes.

The Knowledge Exchange's scoped activity resulted in this study, which aims to identify approaches to scaling up reproducibility in research institutions. This section explores relevant frameworks to show how this problem was broken down to identify a more nuanced approach focused on meso-level approaches, and provides an overview of meso-level approaches to reproducibility in research institutions to identify factors or relevance to scaling up of reproducibility practices.

2.1 Relevant frameworks

The ecosystem around reproducibility is complex, involving stakeholders at multiple levels. For example, agendas such as open science which support reproducibility are highlighted at international policy levels (UNESCO, 2021; OECD, 2021) and dozens of national governments now have open science strategies (CoNOSC, 2022). Other macro-level funding, policy and publishing stakeholders in the international research ecosystem are also increasingly introducing mandates and guidelines to encourage open science practices (Armeni et al., 2021; Begley et al., 2015; Chiarelli et al., 2021; Cobey et al., 2023;

status of reproducibility in the research sector is the diffusion of innovation model (Rogers, 2003). This model theorises how, why, and at what rate innovations (such as new ideas and technology) spread. The model identifies five types of adopters based on their category of innovation adoption: innovators, early adopters, early majority, late majority, and laggards. The transition in uptake from early adopters to early majority is considered critical in achieving critical mass, or the point where the innovation idea becomes self-sustaining.

This study began with the assumption that reproducibility has progressed through the state of being led by innovators, and is now beginning to transition from mostly being implemented by early adopters to being of interest to the early majority, and seeks to understand how to support this key advance. This transition does not mean that the evolution of reproducibility practice by innovators has stopped, but that the awareness of reproducibility has reached a sizable portion of those involved in research. This is based on growing recognition that reproducibility (and more broadly, open science) is moving from the early adopter to early majority phase, at least in some research institutions, geographic areas and/or disciplines (Armeni et al., 2021) This recognition includes focus on scaling up practices, such as webinars on implementing open science at scale (Turing Way, 2023). However, some research suggests that adoption of reproducibility may be slightly further behind that of open science; as shown in a comparison between various open science policy landscapes in table 1: open access, open and FAIR (Findable, Accessible, Interoperable, Reusable) data, and reproducibility. In the table ticks identify those areas with steps have been taken, and without as those where steps are needed.

Nosek integrates the diffusion of innovation model with his strategy for culture change (Nosek, 2019) to provide

European Commission Directorate-General for Research and Innovation et al., 2022). To place the role of research organisations and their staff within this broader ecosystem, three frameworks are identified for framing the focus of this report.

2.1.1 Diffusion of innovation model

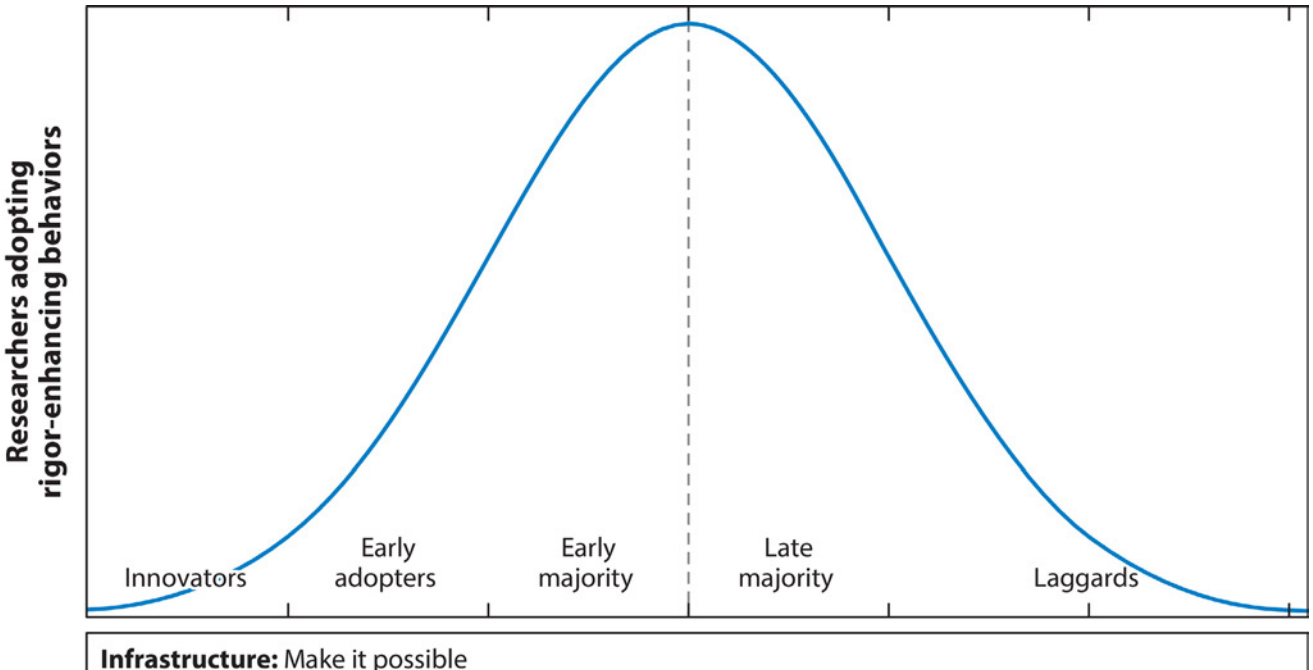
One useful framework for understanding the current

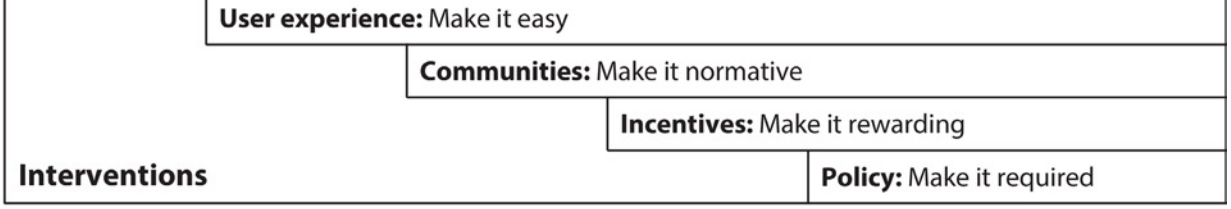
insights into what is needed to support transitions through different stages, as shown in figure 1.

Table 1: Comparison between open science policy landscapes (Chiarelli et al., 2021)

	Open access and policy landscape	Open and FAIR data policy landscape	Reproducibility landscape
Problem definition	✓	✓	✓
Policy development	✓	✓	✓
Policy implementation	✓	✓	
Policy enforcement	✓		
Policy evaluation	✓		

Figure 1: Interdependent interventions for effective culture change extending Roger's 2003 diffusion model (Nosek et al., 2022). Reprinted with permission from the Annual Review of Psychology, Volume 73 © 2022 by Annual Reviews, http://www.annualreviews.org




User experience: Make it easy
Communities: Make it normative
Incentives: Make it rewarding
Interventions
Policy: Make it required

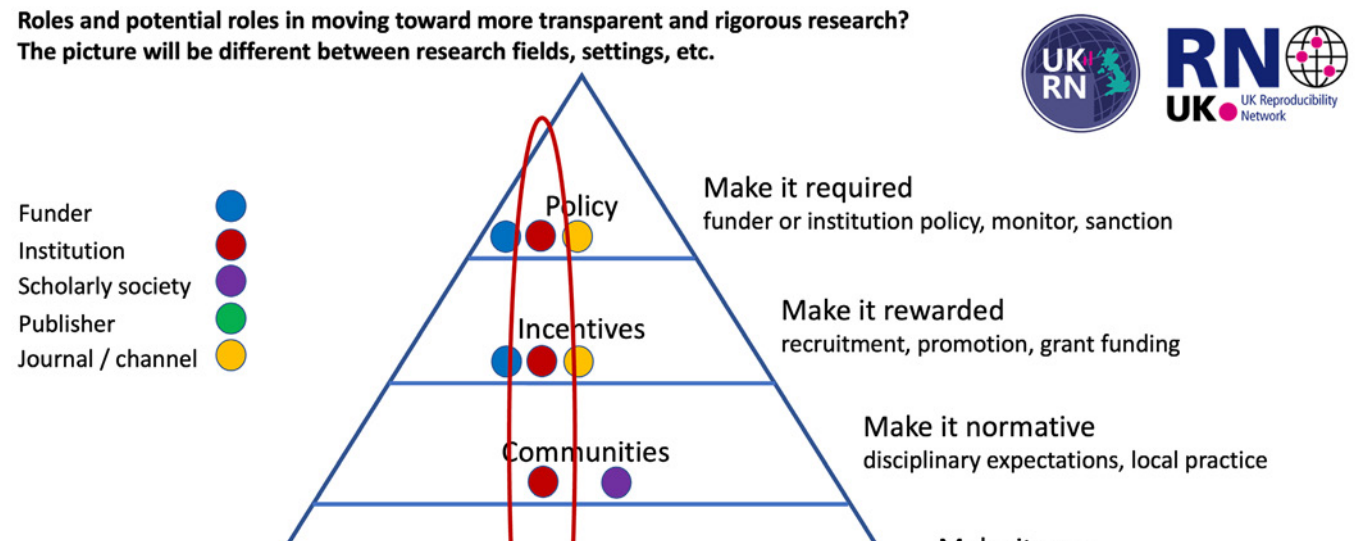
According to Nosek's interpretation of the diffusion of innovation model, the first members of the research community seeking to make their research reproducible need basic infrastructure to make this possible. The small group within the research community who are able to engage with emerging infrastructures can be designated as innovators. To adopt research reproducibility practices, the next group of research community members, the early adopters, also require user experience enablers (which can also be reframed as skills and training enablers) that make it easy. Communities and incentives are then required to bring the early and late majority on board; and policy is needed to incentivise the final group, the laggards.

The role of different stakeholders can also be mapped to Nosek's interpretation of the diffusion of innovation model to suggest that research organisations can play a role in facilitating all parts of the Nosek model, as shown in figure 2.

Consequently, this study aimed to focus on the practices (or interventions) needed to transition from adoption by early adopters to by early majority, which includes a focus on transitioning from the related parts of the model: from a focus on user experience (or skills and training) to that of communities.

Other research supports this study's focus on these transition points in relation to the broader agenda of open science adoption. During a National Academies of Science, Engineering, and Medicine workshop to develop an open science toolkit, Julia Stewart Lowndes also emphasised the communities element in the Nosek model: "We have made progress to make open science possible, easy, rewarding, and required, in some cases, as part of our fundamental processes. Now ... we need to support researchers to make it normative, which requires investing in human infrastructure" (Committee on Developing a Toolkit for Fostering Open Science Practices: A Workshop et al., 2021). Other examples

Figure 2: Behaviour change (Roesch, 2023). Licence: CC-BY




Enabling environment
workflows, interfaces, training
Basic environment
Make it possible
infrastructure, funding, time

include recommendations that early career researchers (ECRs) directly involved in initiatives or activities to change research culture and practice, and the stakeholders who wish to support ECRs in these efforts, should focus on areas such as community building, and amplification of messages through this (Kent et al., 2022).

Whilst this study aimed to focus on the practices needed to transition from adoption by early adopters to early majority, it was recognised that change does not always proceed in the linear manner depicted in Nosek's model, and that it was possible that all five types of practices would be important. Support for consideration of all five types of practices suggested in Nosek's model as important includes analysis of the practices to support publication of reproducible research outputs, which identified the following possible roles and responsibilities for research performing organisations (italics added to highlight alignment):

- Setting **policy** expectations for staff (e.g. sharing of data objects, extent of checking required, disciplinary differences) in the broader context of open science practices.
- Raising awareness of key requirements arising from **policy** expectations.
- Providing **support** via an appropriate mix of data stewards, research object curators or subject librarians.
- Providing general and discipline-specific **training** (for students and staff) to meet the expectations of publishers and research funding organisations.
- Providing access to an appropriate mix of digital and physical **infrastructure** to underpin reproducible research workflows.
- Providing **funding** for reproducibility-related tools during their start-up/pilot phase
- Developing and implementing **reward** mechanisms for reproducible publication practices in the broader criteria for **appointment/promotion** to value researcher behaviours and outputs (Macleod & the University of Edinburgh Research Strategy Group, 2022). Another analysis on how research institutions can make research culture more open included emphasis on establishing or joining **communities** of different stakeholders, publishing an open research statement (or **policy**), **incentivising** with an open research competition and **support** for roles such as research software engineers, and introducing open research criteria into recruitment and **reward** processes (Yaqoob & Darby, 2021).

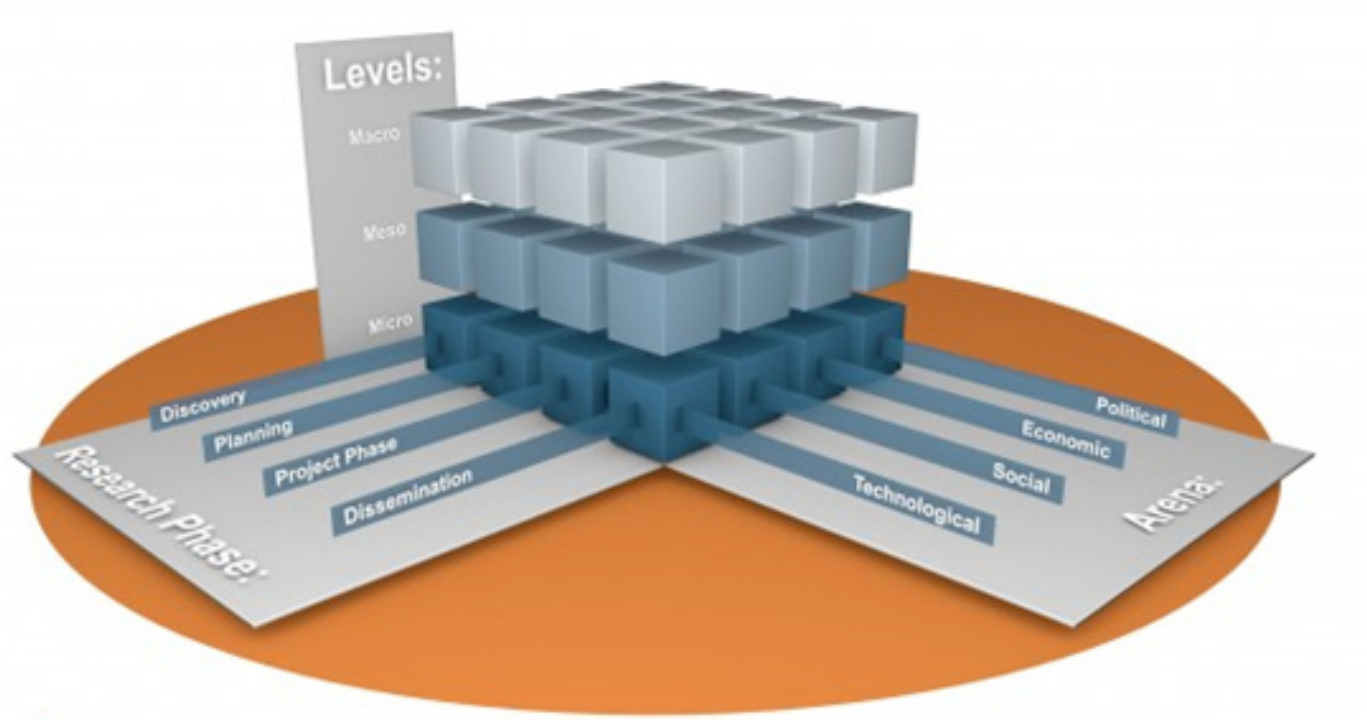
However, there is also some consensus that the infrastructure element of the Nosek model, which can be seen as the initial step in the diffusion of innovation, has been adequately addressed in the case of reproducibility:

- Reproducible publication practices require a range of technological solutions, but most contributors agreed that these are already available in today's research landscape. The key technical gap appears to be the interoperability between available tools and workflows; however, … technological solutions for reproducibility are not currently covered as part of training curricula (Chiarelli et al., 2021).
- Several projects have attempted to address some of the technical aspects of reproducibility by making it easier for authors to disseminate fully reproducible workflows and data, and for readers to perform computations. …. Even though these tools are widely available and seem to address many of the issues of **technical reproducibility** and the **culture of reproducibility**, they have not yet become a core part of the life sciences experimental and publication lifecycle. There is an apparent disconnection between the development of tools addressing reproducibility and their use by the wider scientific and publishing communities who might benefit from

context of open science **practices** (Chiarelli et al., 2021).

Suggestions on how research institutions can improve research reproducibility and integrity also show the need for consideration of multiple parts of Nosek's model, such as: richer and deeper **training and education** in rigorous research practices; and change

Figure 3: Knowledge Exchange Open Scholarship Framework (Knowledge Exchange, 2017)



2.1.2 Knowledge Exchange Open Scholarship Framework

Another useful framework for refining the framing provided by Nosek, is the Knowledge Exchange Open Scholarship Framework (Knowledge Exchange, 2017). This provides a matrix of all the elements necessary to change research culture to increase research reproducibility for a variety of stakeholders, as shown in figure 3.

The Knowledge Exchange Open Scholarship Framework defines the three levels of granularity (shown on the vertical axis) as follows:

- Micro refers to individual actors, e.g. an individual researcher, research-adjacent support staff, or
  government, national/regional funder, or general regulatory framework (Neylon et al., 2019).

This study chose to focus on the meso-level of the framework as this would be most relevant to the research institution focus of this study, noting that the meso-level encompasses a very broad grouping, including informal activities or grassroots communities that are established by individuals who are not managers:

It includes research groups, departments and universities (and groupings of universities), but also includes overlapping organisational groupings like disciplinary communities, scholarly societies, methodological groupings, professional societies and potentially other identity groups if they are relevant

member of the public.

- Meso occupies the space between, referring to groups, organisations and communities e.g. a university, publisher, disciplinary community, scholar society, professional society, or commercial service provider company.
- Macro refers to the system as a whole, e.g. a

Meso-level groupings can be formally organised with an institutional or organisational form, or can be entirely informal. Membership may be well dea ed or diffuse and shared culture and practices may be strong or unclear. Meso-level actors are all those groups made up of micro-level actors or groupings of other meso-level actors that do not include the entire system. They may

or may not be well defined groups and can overlap. Micro- and meso-level actors can be members of multiple non-overlapping meso-level grouping (Neylon et al., 2019).

While this study focuses on the role of specific stakeholders in increasing reproducibility in a particular part of the research ecosystem with the intent of increasing understanding on this aspect, it should be emphasised that other stakeholders are also important: "Simple solutions for achieving reproducible and replicable science are inherently impossible because of the sheer complexity of science. Indeed, culture change can require many different actions, from multiple stakeholders, who each have different priorities" (Rethlefsen et al., 2022).

This focus on the meso-level may also be a useful addition to the literature, which has been found as focusing more on examining macro-levels through policy, funding and publishing initiatives (European Commission Directorate General for Research and Innovation et al., 2022). In areas such as Open Access there has also been considerable focus on the micro-level, particularly the micro-level economics of individuals and their actions: "We have failed to focus sufficiently on how actors at the meso-level (i.e. groups, communities, organisations and institutions) structure the choices that individuals make. For example, we have not rigorously examined how shared culture and norms of behaviour can override both policy mandates and incentives for individual scholars (Neylon et al., 2019).

2.1.3 Taxonomy of interventions

The third framework of relevance to this study is the taxonomy of interventions at academic institutions to improve research quality (Davidson et al., 2022). This taxonomy was the result of a review which identified and classified possible interventions to improve

analysis in this study, and has high levels of similarity to other taxonomies that could have been utilised (Nosek, 2019; UNESCO, 2021). However, it should be noted that the Davidson et al. taxonomy was designed to identify interventions that support different stages of research, in addition to overall research practices, whilst this study focused only on the latter.

The classifications utilised in this taxonomy were adapted for this study (based on the literature review) to focus specifically on reproducibility through inclusion of some examples, as follows:

1. Tools, such as:
   - Available open source and reproducible software packages.
   - Peer-to-peer tool sharing.
   - Study design specific protocol templates for protocol writing.
   - Shared version control repositories for research conduct and analysis.
2. Education and training in research reproducibility, such as:
   - Training on use of reporting guidelines including protocols and registration.
   - Training of research assistants, etc., about reproducibility.
   - Training on research software engineering practices.
3. Incentives to enhance awareness, accessibility and understanding, such as:
   - Hiring and promotion criteria that include open science practices.
   - Awarding small grants/prizes for adhering to best methodological practice.
   - Inclusion of code/data sharing in promotion

reproducibility and replicability within research-performing institutions. Seven major classifications were developed: tools, education and training, incentives, modelling and mentoring, review and feedback, expert involvement, and policies and procedures.

This taxonomy was used as the basis for much of the

4. Modelling and mentoring to encourage research reproducibility, such as:

   - Creation of research teams with an effective mix of research expertise.
   - Programs enabling mentor/mentee partnerships.

- Encouragement of protocol publication during manuscript writing.
- Creating or joining an institutional journal club, or national reproducibility network.

5. Review and feedback, such as:

   - Education for early career researchers on how to conduct peer review.
   - Proposal, grant, manuscript and code peer-review.

6. Expert involvement and advice, such as:

   - Specific hiring for roles with experience of open research, data stewardship, research software engineering, etc. and/or training those currently employed to do this.
   - Availability of a dedicated data champion during research conduct and analysis.

7. Policies and procedures, such as:

   - Mandated study registration during protocol writing
   - Requirement for data and software management plans and integrity checks during research conduct and analysis
   - Research object depositing/sharing policies (including, data, code, physical etc)

2.2 Meso-level approaches to reproducibility

This section provides an overview of meso-level approaches to reproducibility in research institutions to identify factors or relevance to scaling up of reproducibility practices. Approaches to reproducibility in research organisations is considered at a general level, and literature on the approaches of specific research institutions is integrated into section four. And whilst the majority of the focus is on research

to discourage poor-quality science or to foster objectivity" (Begley et al., 2015), and a 2021 exploration nuanced this to conclude that research performing organisations typically:

- Do not have dedicated policies focusing on research reproducibility. It is, however, increasingly common to mention reproducibility in passing, in the context of other institutional policies or requirements.
- Do not tend to mandate reproducible publication practices: Reproducibility efforts are not currently incentivised within the research process, and reproducible publication practices are commonly perceived as additional, unrewarded activities (Chiarelli et al., 2021).

What is generally agreed on is that research institutions have a role to play within the broader research ecosystem in increasing reproducibility (Chiarelli et al., 2021; Kohrs et al., 2023; Macleod & the University of Edinburgh Research Strategy Group, 2022; McIntosh & Hudson Vitale, 2023; UNESCO, 2022; Yaqoob & Darby, 2021). For example, a study of which open science practices would be valuable for research institutions to monitor identified 19 open science practices that could be valuable for institutional monitoring, which included items relevant to reproducibility such as reporting on whether clinical trials were registered before they started recruitment, and whether study data were shared openly at the time of publication (Cobey et al., 2023). Many challenges are also noted related to the role of research institutions in improving reproducibility of the research endeavour, including business models, infrastructure, personnel, and the challenge of monitoring compliance (Begley et al., 2015; Cobey et al., 2023).

The importance of linkage of the roles of institutions with other stakeholders, particularly macro-level funders and policy makers is another area noted as important: "... in most cases, reproducible research practices are

also included.

2.2.1 Research institutions

The focus on reproducibility within research organisations is increasing but needs considerably more focus. A 2015 US-focused study concluded that "few institutions have strong, transparent processes in place not part of funder mandates. As a result of this, it is likely that research performing organisations will continue to monitor the landscape and address research reproducibility via ad-hoc approaches and based on their individual strategies and researcher bases" (Chiarelli et al., 2021). However, coordination would be highly beneficial. For example, one study suggests that: "Institutions, guided by sectoral

organisations such as Universities UK, should coordinate and adopt common policies, guidance, and training for monitoring and improving reproducibility, openness, and quality" (Stewart et al., 2022).

There is also a range of literature that looks more broadly at approaches to supporting reproducibility, such as an analysis of interdisciplinary strategies that identified thirteen approaches that were mapped to Nosek's strategies for culture change (Rethlefsen et al., 2022). This research concluded that:

… multiple approaches are both necessary to address the complexities of implementing reproducible research and [being] welcomed by researchers, who span disciplines and career stages and are therefore not a monolithic group with identical motivations and needs. Whereas top-down policy changes may be effective to spur institutions and principal investigators to make major, potentially costly changes, bottom-up approaches can engage those who are more curious and çexible in making incremental changes to their practices—and who may band together to shift norms through collective efforts (Rethlefsen et al., 2022).

2.2.2 Stakeholders within research institutions

It is also clear that there are many stakeholders within a research institution who can play a role in scaling up reproducibility practices internally. At the micro-level, researchers have a key role, with their roles and responsibilities identified as potentially including:

- Fostering and applying reproducible workflows, including data and code gathering and curation.
- Sharing appropriate research objects (digital and physical) alongside publications.
- Testing articles for reproducibility, when acting as peer reviewers (Chiarelli et al., 2021).

At the meso-level, research organisation areas which

- Setting policy expectations for staff (e.g. sharing of data objects, extent of checking required, disciplinary differences) in the broader context of open science practices.
- Raising awareness of key requirements arising from policy expectations.
- Providing support via an appropriate mix of data stewards, research object curators or subject librarians.
- Providing general and discipline-specific training (for students and staff) to meet the expectations of publishers and research funding organisations.
- Providing access to an appropriate mix of digital and physical infrastructure to underpin reproducible research workflows.
- Providing funding for reproducibility-related tools during their start-up/pilot phase.
- Developing and implementing reward mechanisms for reproducible publication practices in the broader context of open science practices (Chiarelli et al., 2021).

2.2.3 Other meso-level initiatives

There are a range of other meso-level initiatives of relevance, and some analysis has been undertaken on the roles and responsibilities of some of these (Chiarelli et al., 2021). Some that emerged repeatedly during the literature review included publishers and journals, reproducibility networks, disciplinary groups, infrastructure providers, and a range of other communities (including those focused on the FAIR Principles, training and specific roles), with the most commonly mentioned of the many initiatives that exist being:

National Reproducibility Networks: National, peer-led consortiums of researchers that aim to promote and ensure rigorous research practices by establishing appropriate training activities, designing and evaluating research improvement efforts, disseminating best practice and working with stakeholders to coordinate efforts across the sector (UKRN, 2023a).

could take on roles include research administration, academic units, research compliance, information technology, libraries, scholarly communication, researcher appointment and tenure, and institutional metrics or reporting (Cobey et al., 2023; Rethlefsen et al., 2022). These research organisation areas can undertake a range of activities to encourage behavioural change, with possible functions including:

ReproducibiliTea: A world-wide, volunteer-run, grassroots journal club initiative that helps researchers create local open science journal clubs at their universities to discuss diverse issues, papers and ideas about improving science, reproducibility and the open science movement (ReproducibiliTea, 2023).

The Carpentries: An international not-for-profit organisation that teaches foundational coding and data science skills to researchers worldwide. The Carpentries builds global capacity in essential data and computational skills for conducting efficient, open, and reproducible research (The Carpentries, 2023).

ReproHack: An event during which participants attempt to reproduce published research of their choice from a list of proposed papers with publicly available associated code and data. These aim to facilitate and help normalise the activity of research code reviewing (ReproHack, 2023).

Journal of Open Source Software (JOSS):
A developer friendly, open access journal for research software packages. It is designed to improve the quality of the software submitted (JOSS, 2020).

3. Methodology and findings

This section explains the three elements of the study design, the demographics of the respondents, and methodological challenges. It also describes the **æadings from the survey, interviews, focus groups and** community engagement.

3.1 Study design

This study involved a mixed methods approach to enable triangulation of data to maximise validity and reliability of the methodology and findings. It consisted of three stages:

- **Stage one:** Literature review and consultations with key stakeholders
- **Stage two:** Survey and interviews
- **Stage three:** Focus groups and community engagement

Stage one gathered data through literature review and consultations with key stakeholders, to help define the study's questions and scope. The literature review focused on a range of overlapping areas, including reproducibility, open science, research assessment reform, and FAIR practices, which are recognised as highly conducive to reproducible research practices (for example, see Chiarelli et al., 2021). The consultations with key stakeholders engaged two experts in the field in defining study questions and scope, to support the literature review.

Stage two tested the findings of stage one through surveys and interviews to confirm if participants identified similar priority areas for scaling up reproducibility practices, and their perceptions of what was needed to achieve this. The survey questions (contained in Appendix B) sought information on demographics, reproducibility practices that the participants engaged with and/or supported, and what influenced their adoption and/or promotion of practices to increase scaling up of reproducibility. The survey questions were based on analysis of work including individual and organisational decision making, and barriers to engagement with reproducibility and open science for researchers (Alrasheedi et al., 2016; Gownaris et al., 2022; Murphy et al., 2022; Omarli, 2017; Turing Way Community, n.d.; Turner et al., 2017; Zečević et al., 2020). organisational characteristics are relevant, and identify what needs to be in place at micro, meso and/or macro-levels to support new practices; increase the use cases being studied to enable insight into differences; and enable contrasting of situations where reproducibility is common practice, with situations where reproducible research has no uptake at all. The interview consent form and questions are contained in Appendix C. Analysis was undertaken using qualitative data analysis, with initial coding grouping large amounts of text into code. Categories were then created from these codes that mapped to the seven enablers in the Davidson et al. taxonomy, with additional categories also emerging around what would become the framework levels.

Stage three incorporated focus groups and community engagement to gain feedback on the emerging framework's levels, enablers and assessment worksheet. Questions focused on whether the study's findings at that point also reflected the experience of focus group participants, and could help their organisations understand their approach to reproducibility practices. Additional questions investigated what persuades people in senior positions to consider taking a more coordinated approach to reproducibility practice in their organisation; the characteristics of an organisation that should be considered when understanding if a practice might work at a similar organisation; and what may be on the horizon that will have a significant impact on the way that research organisations consider and practice reproducibility. The focus group consent form is contained in Appendix D.

Stage three also included community engagement with the International Reproducibility Network, in recognition of the key role that national reproducibility networks have in enhancing reproducibility in research institutions. The questions utilised for this community engagement were similar to those employed for the focus groups,

Analysis was undertaken using the LimeSurvey platform used for the survey. The anonymised survey data is publicly available (10.5281/zenodo.10666198) with this report.

The interviews aimed to build on the findings on the survey; and specifically to increase identification of specific practices of value; understand if there is order in which practices should take place, consider if reproducibility networks could support Knowledge Exchange's work in this area, and vice versa.

In terms of ethical considerations, the study followed the guidance from the UK Research and Integrity Office on research ethics and integrity, with the study being reviewed by the Knowledge Exchange leads and

overseen by the Knowledge Exchange office. Demographic questions related to gender identity were not included in any of the study elements, because gender identity did not appear to be directly relevant to the aim of identifying practices for scaling up reproducibility. Analysis of the interviews included a code on gender identity to enable easy recognition if in fact gender identity was relevant; but there were no comments on this. However, it should be noted that gender identity could affect whether an individual has the ability to initiate relevant changes within their organisation, with a range of research noting gender inequalities in senior roles in research organisations (Allen et al., 2021; Magliano et al., 2020).

3.2 Demographics

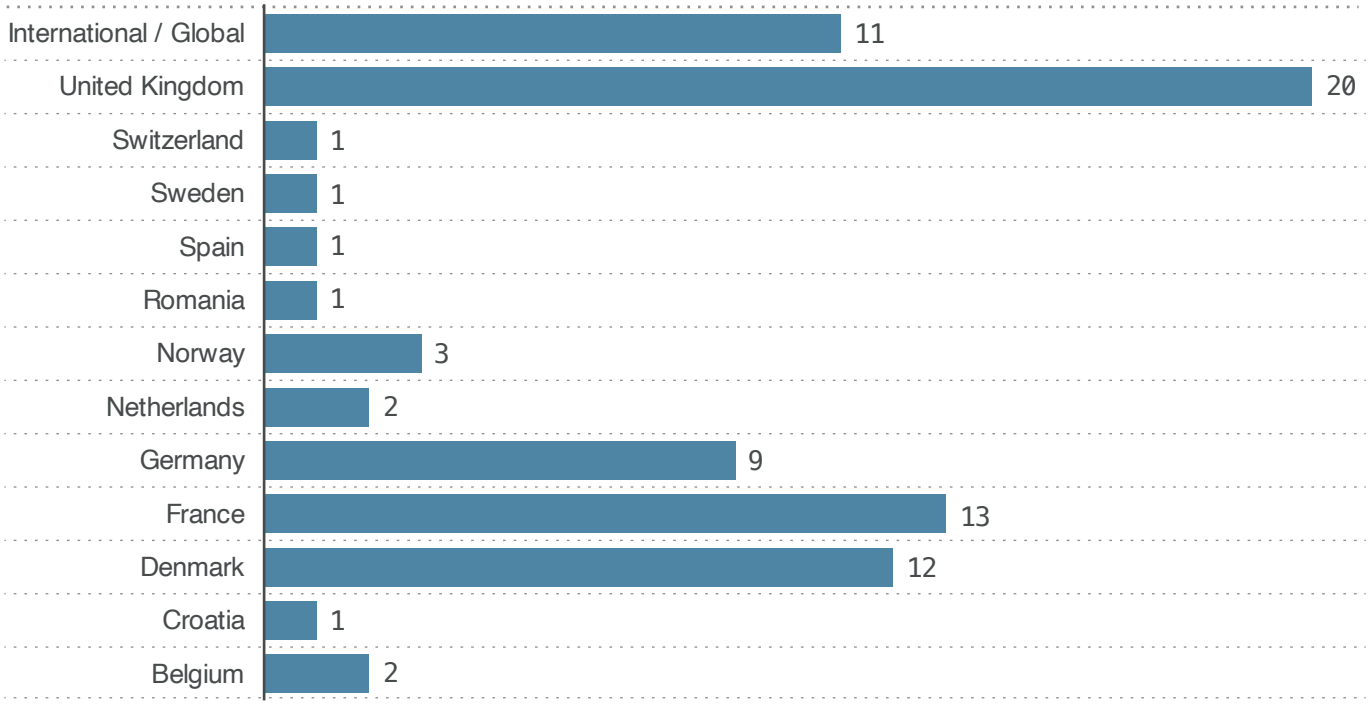
Details are provided here on how participants were recruited for each stage of the study, and the participant demographics. In general, the study focused on input from personnel in research organisations (e.g. universities and research laboratories) whose role potentially included the practice and/or support of research reproducibility in any of the following categories:

- Researchers and/or research-adjacent support staff, e.g. Research Assistant, PhD student, Postdoctoral Research Fellow, Senior Lecturer, Professors, Data Stewards, Research Software Engineer, Data Librarian, Technician, Research Officer, Data Scientist, Academic Librarian, etc.
- Managers of academic/research areas, e.g. Dean, Head of Department, Head of Centre, Group Leaders, etc.
- Managers of research support/infrastructure areas, e.g. Senior Librarian, Data Steward Group Leader, Manager/Director/Group Leader of areas such as IT Services, Technology Transfer Office, Research Office, Library Services, Research Computing, etc.

This focus had one potential limitation in that it omitted

progressed, such as mentors, instructors, members of curriculum committees, hiring and promotion committees, institutional leadership, and administration staff. However, many of the interviewees did encompass these roles. Additionally, one of the key publications in this area did include this breadth, and this work is cited extensively in this study (Kohrs et al., 2023).

Figure 4: Survey respondents by geographic location



3.2.1 Survey participants

The survey was distributed through a range of channels:

- Knowledge Exchange news (Knowledge Exchange, 2023).
- Various Twitter profiles, e.g. Knowledge Exchange 12 May and 24 May 2023, with retweets from organisations including the national reproducibility networks of Belgium, Denmark, Germany, Italy, Norway, Switzerland and UK; DFG; Ireland's National Open Research Forum (NORF); Research Data Alliance (RDA); and Research Software Alliance (ReSA).
- Various Slack channels, Mastodon accounts and LinkedIn posts.
- Newsletters from organisations including the

information, leaving 77 usable responses, of which 51 completed all questions in the survey. The relatively low number of usable responses means that the survey analysis will provide indications of possible patterns rather than firm conclusions.

The majority of the 77 respondents included in the analysis were researchers/research-adjacent support staff (75%), with the remaining being in a management position; and based at a higher education institution (77%), with research institute (17%) being the next most common place of work.

Participants were mostly based in Denmark, France, Germany and the United Kingdom, with others in other European countries. 11 participants were from outside

Software Sustainability Institute, ReSA and UK Reproducibility Network.

The survey was launched on 11 May 2023. At the close of the survey in August 2023, 123 people had interacted with the survey. 46 responses were classified as unusable due to lack of consent or lack of

Europe or considered themselves global, as shown in figure 4. While participants for the study were primarily recruited from European research-performing organisations due to the focus on Knowledge Exchange stakeholders, the work aims to be relevant within the global context.

Figure 5: Survey respondents working by disciplinary field (Note: respondents could choose multiple fields).

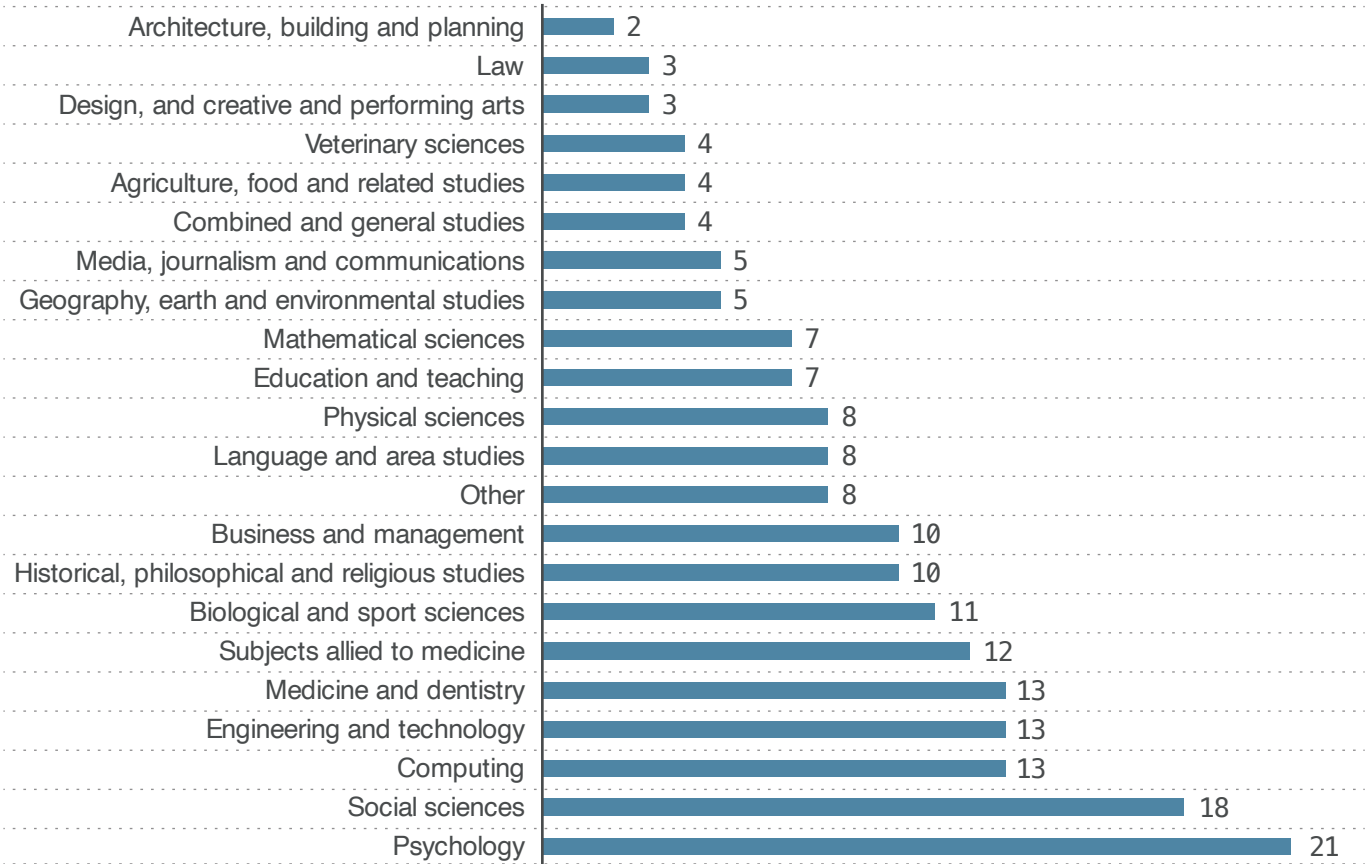
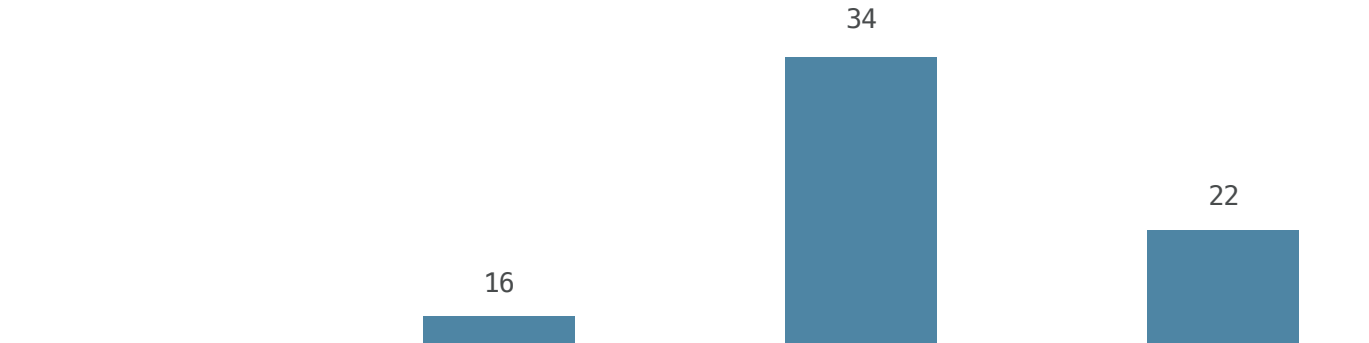
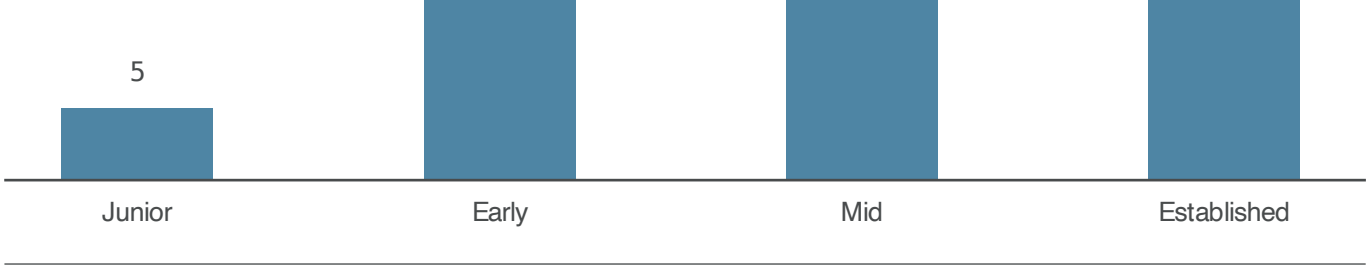


Figure 6: Survey respondents by career stage




5
Junior
Early
Mid
Established

Participants identified as working in a wide range of disciplines, as shown in figure 5. The Common Aggregation Hierarchy (CAH) from the Higher Education Statistics Agency (HESA) was used for the list of disciplines as it provides standard groupings that can be applied to various subject code schemes to enable better comparison against other research that uses disciplinary analysis.

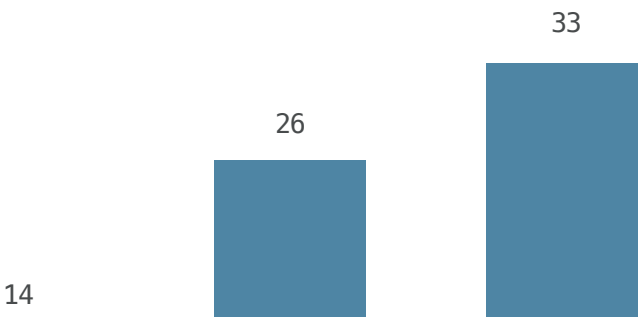
Survey participants were also asked to indicate their career stage, as shown in figure 6. The career levels were defined as follows:

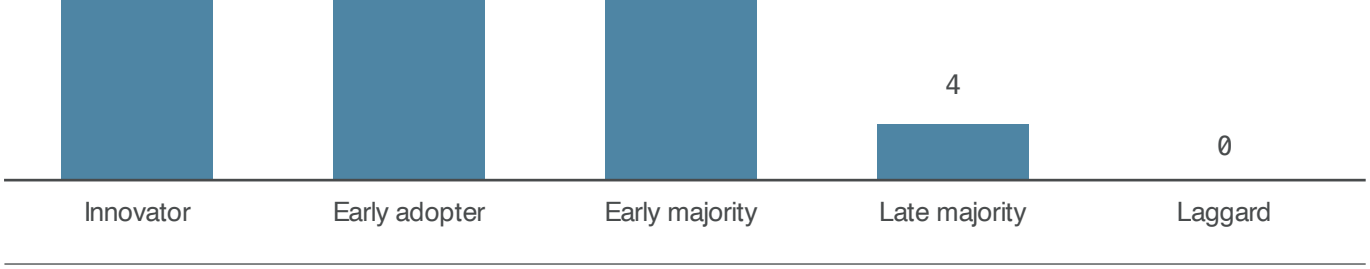
- Junior: (you are studying/training). PhD student, Research Assistant, Assistant Librarian, Junior Research Software Engineer, etc
- Early career: (your work is directed by someone else). Postdoctoral Research Associate, Lecturer; Academic Librarian, Research Librarian, Research Software Engineer, Data Steward, Data Librarian, Technician, Research Officer, etc
- Mid-career: (you're starting to have responsibility for your own work) Research Fellow, Senior Lecturer, Reader, Senior Librarian, Senior Research Software Engineer, Data Steward Group Leader, Senior Data Scientist, Research Manager, Group Leader, Head of Centre, etc
- Established/Senior: (you're in charge of multiple groups). Professor, Professorial Fellow, Head Librarian, Director of Library Services, Head of Department, Director of Research Computing, Service Director, etc

Survey participants were asked a screening question on their opinion of reproducibility to determine which category of adopter (based on diffusion of innovation categories) they identified with. As expected, figure 7 shows that survey participants were mostly adopters of practice because of the routes the survey was advertised and the perceived benefits of completing the survey. In the survey analysis that follows, innovators and early adopters are grouped together as early adopters (52%) and early majority and late majority respondents together as late adopters (48%).

From the demographics of the survey respondents summarised above, it is clear that the data collected in this survey cannot be seen as representative of the views of the entire research community. However, it did provide insight into how to refine questions asked in the interview stage to probe areas where there may be differences of opinion and experience, as well as to explore gaps in accessibility and differences in perceptions and priorities between early and late adopters.

Figure 7: Survey respondents by adopter category




4
0
Innovator
Early adopter
Early majority
Late majority
Laggard

3.2.2 Interview participants

Possible interviewees were identified through three different methods: self-nominated in the survey, suggested by Knowledge Exchange colleagues, and/or identified by the authors of this study. 38 people were contacted by email to invite participation in the interviews, and 20 participated.

The interviews aimed for an even spread across the three targeted roles of researchers/research-adjacent support staff, managers of academic/research areas, and managers of research support/infrastructure areas; and to engage a range of career levels, as shown in figure 8.

It can be seen that there was some bias in interviewees towards more senior career levels in managerial roles, as would be expected due to the nature of managerial positions. There was also some overlap between the roles of researcher and academic/research manager, and participants were assigned to each category based on how they answered the majority of the questions.

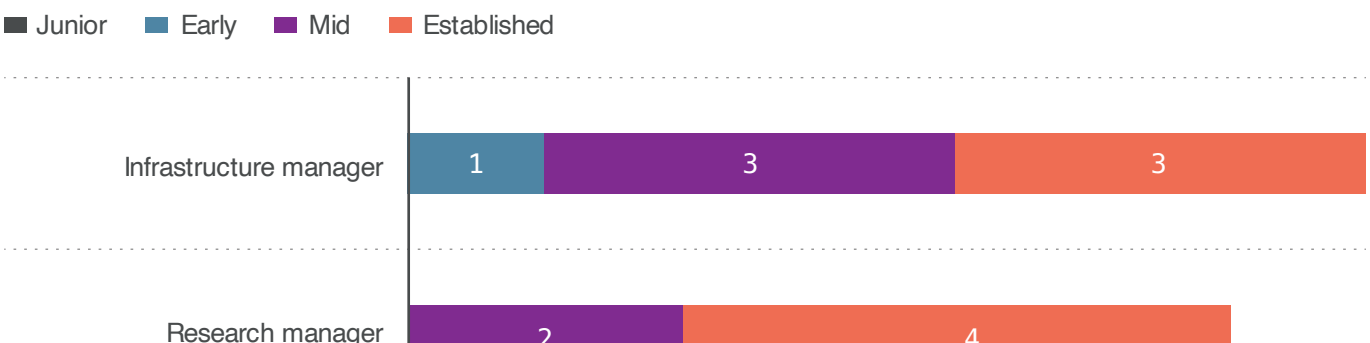
The interviews also aimed to engage participants from across the Knowledge Exchange network member countries (Denmark, Finland, Germany, Netherlands and UK), supplemented with other European countries, as shown in figure 9.

3.2.3 Focus group participants and community engagement

Potential focus group participants were identified by the authors due to their involvement in at least one of the following: the interviews, communities such as the national reproducibility networks, and/or relevant research projects. Nine people were invited to attend one of the two focus groups, and five people participated. The five participants included at least one representative of each of the three target groups of researchers and/or research-adjacent support staff, managers of academic/research areas, and managers of research support/infrastructure areas. Geographic diversity was limited across the five participants to only two countries; however, the breadth of the participants in the community engagement assisted in overcoming this limitation. The focus groups began with a presentation on findings to date to enable feedback, and to continue gaining inputs regarding horizon scanning.

The community engagement focused on discussion with members of the International Reproducibility Network. At least 19 national networks exist (UKRN, 2023a), and the 24 members of the International Reproducibility Network were invited to join a discussion to provide feedback on this study both at a preceding members' meeting, and via email. Eight participants

Figure 8: Interviewee role by career level



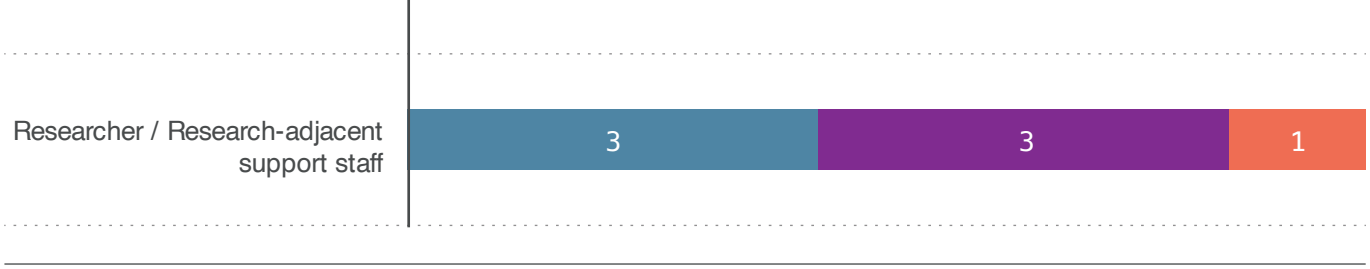

Researcher / Research-adjacent support staff
3
3
1

Figure 9: Interviewee role by geographic location

attended, representing national reproducibility networks from Croatia, Denmark, Finland, Germany, Greece, Netherlands and UK (represented by two participants). Representatives of the Knowledge Exchange also attended this discussion to maximise potential alignment.

3.3. Findings

This section shares high level findings from the survey, interviews, focus groups and community engagement, to illustrate how these shaped the more detailed

reproducibility; in some cases with understanding of the differences but choosing a different focus due to the large overlap of these areas with reproducibility, and in some cases using the terms interchangeably.

3.3.1 Survey results

Analysis of the survey results focussed on three topics: practices that were not working in their current form, differences in priorities between early and late adopters, and differences in practices that early and late adopters

findings and outputs described in section four.

This study defines reproducibility as "the ability of researchers, other than the original researchers, to achieve the same findings using the same data and analysis" (Claerbout & Karrenbach, 1992). However, it should be noted that some participants focused on open science and/or replicability rather than

regarded as working well.

To investigate the first topic, participants were identified who responded that a practice was easily accessible or accessible, but only occasionally or never used it. Any additional comments by those respondents were then examined to understand if there were any common practices to improve reproducibility at a research

organisation which were not working in their current form. These practices included:

- Workshops/drop-in talks to departments which are generic and not focussed on the needs of a discipline.
- Train the trainer initiatives where people were not given specific time to attend.
- Imposition of policies, particularly when they are associated with high fees (e.g. Open Access).
- Advocating for reproducibility without giving people the time to do it.

The answers given to the question of whether respondents saw any risks in encouraging and/or implementing practices that support scaling up of reproducibility were also investigated, which included:

- Hiring committees looking for quantity over quality.
- Mandating reproducibility on busy people will get pushback, because researchers will not see the practices as worthwhile, or be self-motivated.
- Ethical and privacy concerns (particularly in research involving human subjects) around sharing data.
- Collection of data, appropriate data anonymisation and privacy protection measures are all expensive in terms of time and money.
- Encouraging "blanket" open science without considering how the original creators of the data set will be supported will not change norms in these fields.
- A core set of people will be doing the work, and getting more workload, but the benefits are more for other people.

These comments seem to indicate that a primary concern is the introduction of reproducibility interventions without providing those involved with enough time and/or effort to properly adopt them.

To investigate the second topic, respondents were classified into early adopters of reproducibility practices

Early adopters prioritised supporting the practices of education and training, and incentives, for in their organisation; whereas late adopters showed no clear prioritisation across the seven categories of reproducibility practices. In response to the question on what most influenced their adoption, where a range of options beyond the Davidson et al. taxonomy were available, all respondents were influenced by "access to time and financial support" and "potential to increase research impact". However, early adopters favoured "organisational support" whereas late adopters preferred "prevalence of community approaches". Both groups were most likely to have encouraged engagement with practices from the Davidson et al. taxonomy of tools, and education and training. In contrast, early adopters were more likely to encourage modelling and mentoring, whereas late adopters were more likely to encourage policies and procedures.

This suggests, as could be expected from their placement on the diffusion of innovation curve, that late adopters were waiting for community norms to be formed, and clear policies and approaches to be available. However, early adopters looked for organisational support and incentives to establish reproducibility practices and pass these on through direct methods, which implies innovators and early adopters also benefit from the presence of communities and incentives, and that the five interventions identified by Nosek et al. (2022) cannot be seen as a linear progression from infrastructure to policy. Education and Training is clearly important at all stages, but it is unclear why respondents at all levels are most likely to encourage use of Tools, but do not prioritise organisational support for them.

To investigate the third topic, responses were summarised to the question asking respondents if there were any examples of enabling and/or supporting reproducibility in a scalable way that they thought were

versus late adopters, and analysis conducted on their answers to three questions looking at the seven categories of interventions from the Davidson et al. taxonomy: what they would prioritise for support in their organisation, what most influenced their adoption or promotion of practices, and what types of practices to support scaling up reproducibility they had encouraged engagement with at their organisation.

particularly impressive, impactful or innovative. For early adopters, these included:

- Organisational support: Level of senior management buy-in.
- Policies and procedures: Inclusion in hiring and promotion criteria, and annual review; comprehensive and understandable written policies

and procedures that don't take effort to adopt; and change of norms towards reproducible practices in other fields
- Incentives: Small grants for open research, workshops, and events.
- Modelling and mentoring: Personal adoption and use of practice by research group leaders/principal investigators.
- Tools: such as the Open Science Framework, Octopus, RMarkdown; as well as initiatives such as Registered Reports, PREreview, Peer Community In (PCI), ReproducibiliTea, and ReScience C and X journals.

Many of these were considered high effort to implement, but important and innovative.

For late adopters, these included:

- Education and training: ReproducibiliTea seminars are impactful in building a community and helping to shift research culture.
- Organisational support: Employing someone to make papers reproducible.
- Incentives: Incentivisation and reward of peer review and feedback processes.

Overall, the number of respondents means that firm conclusions cannot be drawn from the survey. Nevertheless, the responses point to differences in the way that early adopters and late adopters approach reproducibility, in particular as interventions are scaled up within a research organisation. There is a potential for pushback because interventions are either too generic, implemented too early before the community believes that they will not change, or not associated with time and effort to adopt them. It is useful to identify practices that encourage self-motivation and habit forming, and policies which increase awareness of reproducibility while being easy to implement. However

3.3.2 Interview results

The interviews included four questions that were focused on practices for scaling up reproducibility:

1. Can you tell us about a practice (or practices) to increase scaling of reproducibility that you led, supported and/or highlighted - or that you didn't support?
2. Why did you choose to prioritise engagement with this particular practice over others?
3. What were the positive and/or negative outcomes of this on the personnel it was aimed at (not on you personally)?
4. What advice would you give others who wanted to do something similar, i.e. what factors might affect its implementation in another context, e.g. what might help it be more/less successful?

Building on the findings of the survey, consideration was given as to whether the research organisation that participants were describing practices from could be viewed on the diffusion of innovation spectrum. Analysis of how participants described practices in their organisation, and/or the effects of factors in the organisation that affected uptake of these practices, led to the identification of three levels at which, from a meso-level perspective, organisations could be functioning at, as shown in table 2.

Table 2: Organisational levels

Level 1: Pockets of excellence	Pockets of excellence exist as fragmented, small initiatives, often in research teams, or across individuals with similar concerns.
Level 2: Partially coordinated	There is partial coordination within the organisation, such as within some teams or faculties, or methodologies across disciplines.

particularly conflation of open science and reproducibility, with the result that there is a perception that reproducibility cannot be achieved when research is associated with private data that cannot be shared.

Organisational-level commitment	strategic objectives for the institution as a whole, including expectations of researchers. Processes and structures are coordinated to enable scalability and sustainability.

An organisation may also be functioning at more than one level at once to provide a layering effect; consequently the levels could also be depicted as shown in table 3.

Table 3: Layering of organisational levels

Level 1: Pockets of excellence	**Level 1:** Pockets of excellence	**Level 1:** Pockets of excellence
	Level 2: Partially coordinated	**Level 2:** Partially coordinated
		Level 3: Organisational-level commitment

The analysis of interview participants' answers to these questions included classification of the practices they described in terms of the seven enablers in the Davidson et al. taxonomy.

The coding of the interviews based around the Davidson et al. taxonomy worked well for much of the information, validating the use of this as the basis for this study's framework. Results were further analysed to identify examples of practices that assisted in transitioning between levels, which are described in more detail in the next section.

Analysis of the interviews also evidenced that it could be useful to provide a way for organisations to assess areas where scaling up was already happening, and where more effort could be beneficial. The literature

Responses to some of the questions also lead to coding beyond the Davidson et al. taxonomy, which evolved into consideration of how to support change in research organisations. This also occurred for analysis of the question about any evolving aspects of technology or methods, such as generative artificial intelligence (AI), that may have a particular impact on the ability to scale up this practice and/or reproducibility practices in general.

Analysis of interview data also enabled reflection on the roles of different personnel, particularly those of researchers and research-adjacent support personnel, managers of academic/research areas, and managers of research support/infrastructure areas. The data showed that overall the line is blurred on who is responsible for quality control of research, and those who can facilitate improvement in each of the seven enablers in the Davidson et al. taxonomy. There are a few areas where clarity is a little clearer, e.g. infrastructure managers may have more responsibility for the tools category enablers, and research Managers are likely to have more influence on the modelling and mentoring, and review and feedback categories enablers. Kohrs et al. (2023) provides specific suggestions on actions that various roles can undertake across three main areas of building communities, offering training, and adapting research assessment criteria and program requirements.

3.3.3 Focus group and community engagement results

These discussions included feedback on the levels, enablers and worksheet created from analysis of the preceding work, and horizon scanning for changes that may affect scaling up of reproducibility practices. The participants' feedback in response to the following questions overall provided a high level validation, with additional ideas as follows:

Levels: Does this categorisation reflect what you have

review identified a range of possible tools (Kohrs et al., 2023; Michie et al., 2011; SCVO, 2023; UNESCO, 2022), with the Digital Preservation Coalition's rapid assessment model being chosen as the basis for the development this study's assessment worksheet (Digital Preservation Coalition, 2021).

approach to reproducibility practices?

- The levels correspond with participants' experiences, although it should be emphasised that an organisation can encompass all three levels at once.

- More emphasis would be beneficial in areas such as how to transition from one level to another, the role of bottom-up initiatives at all levels, the importance of senior staff support, and the role of interaction with external communities.
- It should be recognised that different institutions have different concerns, and factors have an influence on ability and willingness to implement, such as size, stage and disciplinary spread.

Enablers: What is the most useful way of presenting this information, e.g. case studies, lists of potential enablers, existing related resources? What characteristics of an organisation should we consider when understanding if an intervention might work at a similar organisation, e.g. organisation size, culture? Are there any enablers or practices that you think would work in any research organisation to improve the coordination or scale of reproducibility practice? Are there any differences you have seen in enablers or practices based on the size of organisation, or the country it is based in?

- Examples and case studies are very useful to enable organisations to understand if the example is about a similar organisation, and to provide evidence that gains are achieved - providing evaluation occurs.
- There was a lot of discussion on the lack of evidence of the efficacy of the interventions. It is possible that an organisation could be at level three, but have implemented practices that don't actually increase reproducibility.

Assessment worksheet: What level of granularity of questions is easiest to answer? What do you find persuades people in senior positions in research organisations to consider taking a more coordinated approach to reproducibility practice in their organisation? Would a framework, checklist, tool and/or case studies help?

input, or different worksheets could be developed for different roles.
- There are a range of ways to influence change, such as comparison with peer institutions, or alignment with organisational vision and risk appetite.
- Some universal enablers across all organisations include external collaboration and internal coordination and alignment.
- Checklists can be beneficial, although it is beneficial if organisation culture shapes the environment to support change, rather than mandating.
- This type of worksheet could also be utilised at the national level.
- There are a wide range of tools and frameworks available for related elements, and this work needs to be situated within these to illustrate its relevance.

Horizon scanning: What do you see on the horizon that will have a significant impact on the way that reproducibility is considered, and practice improved, in research organisations?

- Generative AI can potentially assist in areas such as aggregation of reproducibility data, and analysis of the depth of non-reproducibility. This may motivate institutions to better address this issue, and allow institutions can benchmark against each other
- Generative AI is likely to drive a change in the requirements to show the provenance in experiments, as it becomes difficult to confirm if the research was done.
- Generative AI is facilitating increased discussion about policies across research organisations, which may increase policy development
- Team science will help impact reproducibility at research institutions by lowering barriers between research and research-adjacent support, establishing digital competency centres, and embedding support roles at institutions
- There are pros and cons of reproducibility being

more as a gap analysis, and/or as a catalyst to enable conversations across the organisation.

- It can be beneficial if the emphasis is always positive, identifying what is already being achieved, in addition to opportunities to be even better.
- It needs to be emphasised that a number of different personnel from across the organisation may need to

these are received differently by different stakeholders.

- Equity, diversity, inclusion and access are also interlinked with reproducibility. For example, reproducibility can require acquisition of new skills, potentially increasing burdens on personnel that can lead to mental health consequences.

4. A framework for scaling up reproducibility practices in research organisations

This section presents the main output of this study, the framework for scaling up reproducibility in research institutions. The framework can be used by a range of internal stakeholders with differing goals, such as institutional leaders seeking to align organisational strategies, or managers wishing to provide the support that staff in their part of the organisation may be seeking. Examples and case studies are also provided to help organisations identify their current levels within the framework, and identify target levels. An assessment worksheet and guidelines for usage are also provided as a tool. A shorter version of the framework is also available as a separate document for use by stakeholders.

It is important to understand that this framework is focused on how well organised an organisation is at scaling up reproducibility practices (i.e., access and coordination), not the maturity of reproducibility practices and how well they adhere to what is commonly understood to be best practice in reproducibility.

4.1 Organisational levels

The first part of the framework details levels that a research organisation may progress through (rather than these being benchmarks) in scaling up reproducibility as shown in table 2. The levels are focused on internal aspects of the organisation; however, it is noted in the enablers that external factors can also be highly relevant, and these are addressed later in the guidelines for using the assessment worksheet.

Table 4: Organisational levels in scaling up reproducibility

	Level 1: Pockets of excellence	**Level 2:** Partially coordinated	**Level 3:** Organisational-level commitment
Characteristics	Pockets of excellence exist as fragmented, small initiatives, often in research teams. or across individuals with similar concerns.	There is partial coordination within the organisation, such as within some teams or faculties, or methodologies across disciplines.	Organisational strategy articulates strategic objectives for the institution as a whole, including expectations of researchers. Processes and structures are coordinated to enable scalability and sustainability.
Locus of leadership	Mostly bottom-up.	Combination of bottom up/ top down.	Significant top-down leadership exists but bottom up remains important.
Communities of practice (CoP)	Practice is disseminated by motivated individuals to their peers, but the CoP is typically reliant on these individuals and at a small scale. These may engage and be supported by external communities (e.g. the Carpentries, ReproducibiliTea, disciplinary networks) but often do not have formal support from their own	CoPs start to span departments/faculties, and career stages of participants. There may be some formal support (e.g. a department helping to pay for speakers. catering, or administrative support) but it is still typically reliant on individual effort of volunteers.	There is institutional level engagement with external communities such as the Carpentries, national reproducibility networks, and engagement with national policy of relevance. There are significant established internal CoPs, potentially both institution-specific initiatives, and local expressions of external CoPs.

organisation.

The value of these CoPs is recognised and support is provided as part of the organisational strategy.

Note that all levels can co-exist in the same organisation, particularly in different disciplinary areas; and different levels may be seen as beneficial by different stakeholders with differing goals. It is valuable to consider how to support each level, to access the different levels of innovation that each can offer.

4.2 Enablers of scaling up of reproducibility

The second element of the framework for scaling up reproducibility is enablers. Enablers support or catalyse the transition from one level to another, through a variety of possible practices. The following table provides the high level characteristics of each of the seven enablers (based on the Davidson et al. taxonomy). Each of the enablers are then explored in detail through exploration of a range of examples. This is not a comprehensive list of all possible practices, but identifies examples identified through the literature review, survey, interviews and focus groups.

It should be noted that some of the examples are relevant to multiple enablers and could be placed in multiple parts of the table.

Table 5: Enablers of scaling up reproducibility

	Level 1: Pockets of excellence	**Level 2:** Partially coordinated	**Level 3:** Organisational-level commitment
Tools	Digital tools that support reproducibility are available internally, but the majority of researchers may struggle to understand which infrastructure to use, when and how.	Access to or development of some digital tools is supported by some teams, faculties and/or disciplines, and supported by some training.	Digital tools that support reproducibility are widely utilised, integrated with other organisational tools, highly accessible and user-friendly, and supported by programs and/or personnel that increase awareness and skills.
Education and training	Individuals take responsibility for their own education and training in reproducible practices, mostly from external sources.	Some training exists in certain faculties or across disciplines, but are not creditable or part of formal curricula.	Training is scalable to meet demand, tailored to different stakeholders, and is a creditable, compulsory part of curricula and/or generally available to all.
Incentives	Individuals are intrinsically motivated to undertake reproducibility practices and promote the benefits to their peers/team.	Research leaders in some teams or faculties encourage reproducibility practices in line with their own values and practices, and/or those of their discipline.	Organisational cultures and values incorporate and value reproducibility practices, including research assessment, and hiring and promotion criteria.
Modelling and mentoring	Individuals model reproducibility supporting behaviours to their peers and/or teams.	Small internal communities that share best practice are built in some areas, such as across disciplines or teams in a faculty.	Internal communities are built and supported across the organisation to collaboratively implement reproducibility practices.
Review and feedback	Some research teams may have peer review processes that include reproducibility practices.	Some faculties or research leaders across disciplines may support review and feedback processes that facilitate reproducibility.	Organisational strategies and processes to support reproducibility incorporate review and feedback approaches.
Expert involvement and advice	Advice on reproducibility practices is usually provided by individuals for whom this is not part of their organisational role, but who may have personal	Some areas of the organisation may have access to dedicated roles that include supporting reproducibility, in research	Staff in dedicated roles are supported by organisational strategy and centrally coordinated, with a clear mandate to lead across faculties to achieve

	expertise.	and/or centralised teams.	scalability and sustainability.
Policies and procedures	Individuals may choose to adhere to disciplinary practices related to reproducibility.	Some policies and practices at faculty and/or discipline level set expectations and/or requirements for staff on reproducibility practices.	Organisational policies and procedures set expectations and/or requirements for staff, and evaluation of their efficacy occurs regularly.

4.2.1 Tools

Table 6: Levels of tools enablers

1: Pockets of excellence	Digital tools that support reproducibility are available internally, but the majority of researchers may struggle to understand which infrastructure to use, when and how.
2: Partially coordinated	Access to or development of some digital tools is supported by some faculties and/or disciplines, and supported by some training.
3: Organisational-level commitment	Digital tools that support reproducibility are widely utilised, integrated with other organisational tools, highly accessible and user-friendly, and supported by programs and/or personnel that increase awareness and skills.

As discussed earlier, the provision of infrastructure is to some degree considered a solved problem (Christensen-Dalsgaard, 2023), although lack of interoperability between these can still be an issue (Chiarelli et al., 2021). Various types of digital tools exist to support reproducibility practices, including tools that support preregistration, data repositories, version controlled-code repositories, and preprint and open access archives. Research staff can usually access a wide range of externally available tools, in addition to some internal tools, to ensure best practices are followed.

With crucial infrastructure already in place, it is the imbalance between technical and cultural infrastructures that instead provides challenges around how to improve this case the benefits achieved were that the institutional data infrastructure could be more easily made user-friendly, to encourage use.

Practices which may enable research organisations to transition through different levels of the framework with regard to digital tools as shown in table 6, can include:

- **Identifying key digital tools** used by teams and labs and supporting their adoption at disciplinary, faculty or organisational level. These can include tools to enable peer-to-peer tool sharing; study design specific protocol templates for protocol writing; or shared workflows for research conduct and analysis, based on open source and reproducible software packages. However, it should be noted that some key tools can be quite specialised in their application, and broader adoption may not be warranted.

- **Considering how to utilise other enablers** to maximise the value and use of digital tools, particularly around training and education, or expert involvement. Several interviews focused on this, with examples including:

  - At an institution where it is a national legal requirement that clinical trials are added to a clinical trials registry, the institution centralised responsibility for supporting this process to overcome the problem that some researchers were non-compliant. Research-adjacent support staff support the registration of trials, and monitor that results are subsequently reported.
  - At an organisation with a central research information system, the research data team manages the data deposit workflows of researchers. The research data team works with researchers to ensure that procedures that support reproducibility are met, such as that certain criteria are required before a digital object

usage, and to ensure that reproducibility workflows and checks are as easy as possible for researchers (Chiarelli et al., 2021). For example, one interviewee described a situation where it was beneficial to create institutional data infrastructure and then provide research teams with a choice of using this or the national infrastructure, rather than requiring use of the national infrastructure. In

identifier (DOI) can be assigned for datasets. These include that datasets must have a text (or readme) file that contains key information which include any information on specialist software required to read the data, and that data must be in appropriate format.

4.2.2 Education and training

Table 7: Levels of education and training enablers

1: Pockets of excellence	Individuals take responsibility for their own education and training in reproducible practices, mostly from external sources.
2: Partially coordinated	Some training exists in certain faculties or across disciplines, but are not creditable or part of formal curricula.
3: Organisational-level commitment	Training is scalable to meet demand, tailored to different stakeholders, and is a creditable, compulsory part of curricula and/or generally available to all.

Education and training enable research personnel to understand the importance of reproducibility, to be trained in best practices, and to utilise available tools. There are many examples of education and training to support reproducible practices being provided within research organisations, with many different goals.

Approaches to education and training on reproducibility practices are similar across the three levels, as shown in table 7, with differences arising from whether practices such as the following are coordinated at the level of teams, disciplines, faculties and/or organisation:

- **Training is sustainable and scalable to meet demand.** One interviewee detailed their focus on open training programs (in the spirit of open education), with some of their initial steps involving talking to researchers to identify bottlenecks, then considering what was available: **We wanted to set support scalability and sustainability.** Team teaching can also be valuable within an organisation to enable specialisation in different topics.

- **Training is nuanced,** with ranges from beginner to advanced, addresses specific disciplines/approaches (e.g. sensitive data, reporting guidelines for protocols), and addresses a variety of types of research outputs (e.g. research data and research software). For example, one interviewee explained that their rationale for introducing Software Carpentry training was to improve software engineering practices for the wide range of staff who worked with software but lacked core skills in this area: **We do things like this to create awareness, to give a çavour of what's involved, so they can educate themselves further or get help from professionals in software engineering. We got a lot of positive feedback from both the experienced researchers and doctoral students who attended.**

- **Training is integrated into the curriculum.** For example, Kohrs et al. (2023) provide options such as adding or expanding research methods courses to cover topics such as protocol depositing, open data and code, and rigorous experimental design. Replication can also be performed as course projects. Kohrs et al. also detail specific strategies on integrating reproducibility and open science skills into courses on other topics, such as **"giving a lecture on the implications of the reproducibility crisis and potential solutions in an introductory class, integrating preregistrations into research project courses, using open science tools to analyse and present data during undergraduate practical training, or practising techniques for writing reproducible protocols in laboratory sessions''.**

- **Consideration of how to enable support for curriculum change.** Kohrs et al. highlights that

the goal very low by starting with external training that already existed, and to create a low barrier for involvement by other institutions that might be too small to have their own trainings.

- **Training may be delivered in collaboration with other organisations,** and/or integrate external training curricula (such as the Carpentries) to

top-down and bottom-up approaches, including support from institutional decision makers; and provides advice such as:

- 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 (Kohrs et al., 2023).

- **Education differs for staff and students** and is provided for a wide variety of types of staff. From one interviewee: We have added new courses because someone's asked or we've detected regular problems or questions. For example, where we've been delivering training to postgraduates and staff, then we've identified that actually the two cohorts have different needs. So we've then developed the training separately.

- **Training integrates material from different administrative perspectives,** such as privacy, ethics and intellectual property. One interviewee described how the development of a generic course on research data management addressed this: Through collaboration, we created a course … with the privacy team and with the ethics committee, we managed to engage them all. In contributing to these it also helps their roles, as there is a course that they know is good quality, and with content [that] is in alignment with what they are advising … it makes their job – not sure if it makes it easier, but at least researchers come with the right questions so they don't have to start from the very beginning.

- **Training includes how to encourage peers and/or team members** to also adopt best practices, as implementing reproducible research and open science practices often requires collaboration among members of a research team. Kohrs et al. identify one of the key strategies for making reproducible research to be to conduct educational interventions for research groups, in recognition that researchers who completed a course independently may have

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 (Kohrs et al., 2023).

Heise et al. (2023) also provide advice for this type of situation, noting that training is often organised at a grassroots level, such as training offered by ECRs for ECRs. To support participants who want to implement new practices once they return to their research team, Heise et al. describe ten simple rules to guide participants of relevant training courses in implementing robust research practices in their own projects. This includes prioritising and planning which practises to implement, which involves obtaining support and convincing others involved in the research project of the added value of implementation.

- **Education is a creditable, compulsory part of postgraduate (and maybe undergraduate) curricula.** Some interviewees from level one and two institutions highlighted their desire that reproducibility training be scaled up to the extent that it was mainstreamed (whilst also noting that this is already common in certain disciplines):

  - For ECRs in our faculty the question is not whether they want to do it, as for a master's degree it's not a choice. The people teaching methods class teach this as standard so it's normalised and makes sense to work that way.
  - We have pockets of excellence, but are starting to think if we need to make the training mandatory, or embed it into inductions to make it mandatory.
  - This should just become science, rather than something on top of your research. … Extracurricular classes are usually taken by those who already think it's important, so it needs to become mandatory.

difficulties convincing other members of their research team to invest time and resources into learning and adopting new practices:

- 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

Examples of creditable courses include the University of Vienna's part-time further education program specialising in research data management at research institutions (Vienna University Library, 2023).

- Internal communities are built to increase community

learning opportunities, e.g. journal clubs or grouping of staff with similar roles, such as research software engineers. For example, communities of data champions exist at both the University of Cambridge, UK (Higman et al., 2018; Savage & Cadwallader, 2019) and Delft University of Technology (TU Delft), Netherlands (Clare, 2019). Belgium also has a community of data ambassadors across the six French-speaking Belgian universities, which is modelled on the work of these two universities (Biernaux et al., 2022).

4.2.3 Incentives

Table 8: Levels of incentives enablers

1: Pockets of excellence	Individuals are intrinsically motivated to undertake reproducibility practices and promote the benefits to their peers/team.
2: Partially coordinated	Research leaders in some areas or faculties encourage reproducibility practices in line with their own values and practices, and/or those of their discipline.
3: Organisational-level commitment	Organisational cultures and values incorporate and value reproducibility practices, including research assessment, and hiring and promotion criteria.

It is well acknowledged that systematic efforts to reform research assessment and reward structures are needed to more consistently incentivise behaviours that are conducive to reproducible publication practices, or incentives in research institutions is also noted (Chiarelli et al., 2021; Davidson et al., 2022), with research highlighting that **"implementing hiring practices with open science at the core of research roles will encourage attitudes to change across faculty departments and institutions"** (Samota & Davey, 2021).

Approaches to incentivising reproducibility practices are similar across the three levels of the framework as shown in table 8, with differences arising from whether practices such as the following are provided at the level of teams, disciplines, faculties and/or organisation:

- **Research and researcher appointment and assessment criteria** includes reproducible practices that value researcher behaviours as well as researcher outputs, across a range of research outputs.
  - There is mention of open science contributions as relevant in research role advertisements, and departmental policies on the inclusion of reproducible and open science requirements in academic job descriptions and hiring processes exist. For instance, the Department of Psychology at LMU Munich, Germany, asks professorial applicants to include a statement on how they have already implemented open science practices and plan to further (Kohrs et al., 2023).

  The broader discussion in the research sector on reforming research assessment is also relevant. For example, the University of Exeter, UK, has formed a responsible metrics champions group, whose work includes creation of guiding principles for the responsible use of indicators in research assessment and management (Responsible Metrics Champions Group, n.d.).

- **Some potential solutions identified at the**

broader agendas such as open science (Chiarelli et al., 2021; Yaqoob & Darby, 2021), with Chiarelli et al. (2021) noting that: “The vast majority of researchers hold themselves to high standards: we expect that they will readily adopt reproducible publication practices, as long as a balance is found between increasing expectations and practical rewards”. However, the paucity of relevant

national level include the UK Reproducibility Network’s Open and Responsible Researcher Reward and Recognition Project to support the institutional implementation of responsible researcher assessment policies and procedures that recognise and reward open research (UKRN, 2023b). Yaqoob and Darby also identify the UK Reproducibility Networks’ hiring policies certification

scheme, and the European Union's Open Science Career Assessment Matrix. The Norwegian Career Assessment Matrix (NOR-CAM) is also a modified version of the latter that has been proposed as a national assessment framework in Norway, (Chambers et al., 2023; Directorate-General for Research and Innovation et al., 2017; Yaqoob & Darby, 2021). A proposal also exists in the discipline of psychology for a specific proposal for hiring and promotion criteria that includes elements that support reproducibility (Gärtner et al., 2022).

- **The San Francisco Declaration on Research Assessment (DORA)** and Coalition for Advancing Research Assessment (CoARA) were also repeatedly mentioned as potential catalysts of change. DORA is currently finalising Reformscape, an online tool for exploring examples of how to bring responsible assessment for hiring, promotion and tenure into an institution, and to share this approach with others.

- **Program requirements are adapted to include reproducible practices,** e.g. in student theses (with requirements dependent on the field and program).

  - Guidelines or guiding principles on quality assurance and open science practices in thesis agreements for Bachelor's and Master's programs are part of German psychology departments at Trier University, Saarland University, and Dresden University of Technology. Examples at doctoral level are also provided (Kohrs et al., 2023).

- **Incentives exist for reproducible practices,** e.g. workload models, awards, showcases, grants for adhering to reproducibility practices.

  - Helmholtz Association (a union of 18 scientific-technical and biological-medical research collaboration. (Helmholtz Open Science Office, 2023).
  - University of Michigan, USA: The Reproducibility Challenge promotes reproducible research in data science and AI. In addition to identifying winners, the submission process includes a reproducibility showcase for the teams to share their experience with the research community (Liu et al., 2022).
  - UK Reproducibility Network has published a primer on running an open research award competition (Merrett et al., 2021).

There are also other macro-level awards that provide examples, such as the Centre for Open Science's Preregistration Challenge (Center for Open Science, 2019); and the Swiss Reproducibility Awards 2024 launched by the Swiss National Science Foundation and the Swiss Reproducibility Network. This aims to support and highlight the work of ECRs as well as research teams who are paying special attention to rigour, transparency and reproducibility in their research (Swiss RN, 2023).

- **Dedicated time is provided in work hours** to participate in and attend reproducibility-focused practices and training. For example, completion of reproducibility training could be a mandatory part of employment, building on the model that training in areas such as sexual harassment prevention and research ethics are required for promotion.

centres), Germany. The Helmholtz Incubator Software Award aims to promote the development of professional and high quality research software and to recognise the commitment to software as the basis of modern data science. The award shines a spotlight on the sustainable development and operation of research software, promoting reusability and

4.2.4 Modelling and mentoring

Table 9: Levels of modelling and mentoring enablers

1: Pockets of excellence	Individuals model reproducibility supporting behaviours to their peers and/or teams.
2: Partially coordinated	Small internal communities that share best practice are built in some areas, such as across disciplines or teams in a faculty.
3: Organisational-level commitment	Internal communities are built and supported across the organisation to collaboratively implement reproducibility practices.

Some practices related to reproducibility are being increasingly implemented, such as sharing of data management plans (DMPs), protocols, preprints, and data among survey respondents; whilst other practices such as preregistration and sharing of materials have low uptake (European Commission Directorate General for Research and Innovation et al., 2022). Modelling and mentoring are commonly recognised as a key way to encourage implementation across different levels of the framework as shown in table 9, with its importance being highlighted by several interviewees with comments including the following:

PhD students that collaborate a bit out of their team, with other researchers who have interest in this; they're more prepared to adopt such practices, and they also have experiences of them bringing suggestions of how to change.

When we examined change in research culture in another area, we found at first that people were adverse

Information about modelling and mentoring practices that support reproducibility tend to focus on examples of how to include this focus in these encounters:

- Training a whole team in the same practice, such as protocol publication. One interviewee noted the benefit of their team's establishment of a metadata protocol for their lab. Whilst the short-term aim was to enable sharing across lab members, it also helped team members learn elements of reproducibility that could encourage them to later share their research more openly. Another interviewee highlighted that practices such as regular lab meetings that require each member to share their experimental methodology and process on a regular basis can be valuable for normalising such behaviours.

- Creating research teams with an effective mix of research expertise.

- Establishing informal or formal mentor/mentee partnerships that go beyond sharing of best practice to also provide safe spaces to identify when experiments are not reproducible (particularly if the experiments were completed by peers, collaborators, or well-known scientists). Mentoring relationships can also enable learnings in both directions, with more junior staff modelling and mentoring reproducibility practices to their more senior mentors.

- Project supervisors are able to provide hands-on training in implementing reproducible research.

The role of informal champions was also consistently identified by study participants, noting that having the support of senior staff (such as a team or faculty leader) were critical to success. For example, one interviewee gave an example of how senior staff supported the research office's work in facilitating preregistration

to training, Then over a period of time we noticed a change in their attitude because their peers started to talk about these kind of trainings, and so the environment started to legitimise the need for these kind of trainings, and potentially acknowledge this knowledge as something that might be useful for research.

subsequent outcomes reporting must be completed at the end of the project.

Champions programs were also noted as another way to support scaling up of role modelling and provision of advice by connecting those modelling and championing best practices. The role of champions (or ambassadors)

is noted as an important awareness-raising mechanism by interviewees and in the literature (Chiarelli et al., 2021). For example, establishing an open research champions network within an institution (or beyond) is one option:

Institutions can cultivate allies in the research community who model good practice, amplify communications and propagate knowledge and skills within local networks. … Champions can be supported with funding for activities, such as organising workshops and training, attending courses and events, and participating in open-research-related projects (Yaqoob & Darby, 2021).

An Australian university also utilised modelling and mentoring opportunities to promote academic engagement in research data management that included encouraging professional and academic departments to provide internships that concern research data management, and forums to highlight research data management amongst peers, and assigning staff to research data management-related committees (Gruba & Turpin, 2023).

4.2.5 Review and feedback

Table 10: Levels of review and feedback enablers

1: Pockets of excellence	Some research teams may have peer review processes that include reproducibility practices.
2: Partially coordinated	Some faculties or research leaders across disciplines may support review and feedback processes that facilitate reproducibility.
3:	Organisational strategies and

whole organisations to transition through levels of the framework as shown in table 10, include:

- Education for early career researchers on how to conduct peer review.
- Leadership support for the use of peer review to improve reproducibility of proposals, manuscripts and/or code, and at all stages of the research lifecycle: proposals, protocols, pre- and post-submission of publications (Davidson et al., 2022). This may include access to external review services such as CODECHECK, an approach for independent execution of computations underlying research articles (Nüst, 2023).
- Identification of personnel responsible for undertaking specific types of peer review, and resourcing for this function. For example, two of the interviewees saw benefits in being able to access code review from personnel not involved in the development of the code. One of these interviewees had been discussing the possibilities of creating an organisational role with some similarity to some of research office roles that support researchers and research-adjacent support staff in drafting grant proposals to ensure all requirements are met, but instead support reproducibility: **If I had help like this in something like preregistration of research designs, with different types of templates, and someone who could help me put the data into these templates, this would definitely motivate me to do it. This would speed up my work. Otherwise I literally have to take this time from paper writing, data collection, teaching or supervision.**
- Utilisation of expert involvement to both provide feedback and encourage policy compliance. For example, the University of Exeter, UK, is considering piloting spot checking of reproducibility, and seven universities in the UK Reproducibility Network are

Organisational-level commitment	processes to support reproducibility incorporate review and feedback approaches.

Some of the practices that can be seen utilised by teams, faculties and/or across disciplines, or across

based on a program implemented elsewhere where every three months, three principal investigators and three of their recent articles and/or preprints are randomly chosen. The reproducibility of the tables and figures must be evidenced to an external evaluator who has been provided with the original data (Kelson, 2023).

4.2.6 Expert involvement and advice

Table 11: Levels of expert involvement and advice enablers

1: Pockets of excellence	Advice on reproducibility practices is usually provided by individuals for whom this is not part of their organisational role, but who may have personal expertise.
2: Partially coordinated	Some areas of the organisation may have access to dedicated roles that include supporting reproducibility, in research and/or centralised teams.
3: Organisational-level commitment	Staff in dedicated roles are supported by organisational strategy and centrally coordinated, with a clear mandate to lead across faculties to achieve scalability and sustainability.

The focus on reproducible science is one of the many drivers of recognition of a range of new roles in the research ecosystem, such as data steward, data curator, and research software engineer. It is recognised that researchers cannot encompass the many skills that research now requires, including the management, curation and sharing of research data and methods that are necessary conditions for reproducibility. "It is essential for these practices to become the norm to push the reproducibility agenda forward, and some dedicated institutional roles such as data stewards may be required to keep up with the demand for support" (Chiarelli et al., 2021). Team science is another driver that also delivers research benefits, as it enables

- **Recruitment for specific roles** that support elements of reproducibility, sometimes as part of broader agendas such as open science or research integrity; and/or training for those currently employed to do this. Some parts of the organisation will include staff with these skills in their research teams, and/or faculty-level or centralised pools of staff in these roles may exist. While these roles commonly encompass skills in data stewardship, research software engineering, open science practices, etc.; expert involvement can also be provided in other ways, such as provision of a detailed data champion during research conduct or analysis.

- **Creation of specific role descriptions.** For example, the Netherlands eScience Center has created a comprehensive role description and job profile for research software engineers, which can also serve as resources for others who are looking to define and appropriately position these roles within their organisations (Netherlands eScience Center, 2023a, 2023b; Weiner, 2023).

- **Inclusion of relevant expertise in research-adjacent units** such as the research office or library. These units may be able to provide high level support, e.g. for drafting of DMPs or obtaining DOIs. One interviewee noted that even when research teams or faculties have access to relevant skill sets, there is still valuing of centralised units such as the library as a conduit for this.

- **Resourcing to enable expert staff to provide tailored advice** to individuals at a level that meets demand. A common challenge is that expert staff may not have enough time to scale their services to all that need it. Three interviewees in this situation explained that they need to finely focus their limited resources for one-to-one engagement. One interviewee achieves this by focusing on research

creation of "**conditions in which reproducible science is not only more likely, it is actually easier to conduct than irreproducible science**" (Rolland et al., 2021).

Approaches to utilising expert involvement and advice as a catalyst for increasing reproducibility practices for organisations transitioning through levels of the framework as shown in table 11, include the following:

personnel who have enough familiarity with reproducibility to seek assistance; and another prioritise engagement those completing the open science requirements of a grant application. In the latter case, the organisation has enough staff to offer support to researchers receiving grants, and to contact ECRSs when they commence employment; but not to service the majority of researchers.

Another interviewee noted the benefits of one-to-one engagement by, describing how an open science expert helped a researcher who was sceptical about the value of open science to write a grant proposal that integrated relevant principles: The researcher was delighted that the expert team member agreed that they couldn't share their data as it couldn't be anonymised, but the researcher learned that they do include other reproducibility practices, such as sharing interview guides or simulating data that resembles theirs. Similarly, a third interviewee noted that personal contact with researchers is underrated in their university: We need to speak to researchers to understand what they're doing, what are their own requirements, how things should be done, and the obstacles they're facing in their daily life.

- **Team science is supported to ensure research groups include relevant expertise.** One interviewee described how team science assisted in achieving compliance with funder requirements for data and code sharing: It wasn't that much extra work because we … had an IT researcher in the team who did everything. But I think that if we didn't have an IT person in the team that could literally do it in no time … I'm not sure whether we would seriously consider doing it.

- **Centralised teams are large enough to bring nuanced expertise,** rather than just being one individual. Larger teams can incorporate a range of skills and backgrounds, to better address specific types of reproducibility challenges.

- **Staff in dedicated roles are centrally coordinated to some degree** (regardless of whether centralised or not). Central coordination, mandated by organisational strategy, can assist in clarifying responsibilities, tracking implementation, and identifying resources (including personnel for training) can provide different messaging regarding the importance of reproducibility to research outcomes. This equally applies to where expertise is located. One research participant noted that a scheme to support champions across their institution that had been centrally supported resulted in some of the champions feeling unsupported by their research schools. In contrast, other organisations have begun by placing dedicated staff in faculties, to build evidence of their value to achieve centralised support. Analysis of models on the location of research software engineering teams has similarly shown that a variety of approaches exist (Katz et al., 2019).

Another interviewee concluded that expertise should be located in the part of the universities that researchers trust, and that providing excellent customer experience (such as a single contact point to escalate queries to the right person) is also essential. Another interviewee noted that no matter what the location, another important element is that: We support staff from our side have to show that we are knowledgeable enough to be able to help researchers, and to make clear how this collaboration works between support staff and researchers? And this is also something that takes considerable time.

- **Incorporation of reproducibility leadership in senior roles.** An example of a way to ensure senior leadership is contained in the requirements of membership of the UK Reproducibility Network, whereby to become a member institutions must appoint an Institutional Lead as a formal role within the senior management team (e.g. an Academic Lead for Research Improvement or similar) (UK Reproducibility Network Steering Committee, 2021). The Institutional Lead is charged with supporting the delivery of UK Reproducibility Network activities (training, workshops, policy development, etc.)

that can be used collaboratively.

One interviewee noted that the decision on where to place leadership of reproducibility can have different effects. Whilst many organisations choose an area already involved in supporting education and engagement with open science activities, such as a library, location in a research-focused central unit within the institution (e.g. via undergraduate, postgraduate, postdoctoral, and senior training programmes). The UK Reproducibility Network Terms of Reference include a model role description that includes that Institutional Leads should be provided a time allocation to fulfil the responsibilities of the role (UK Reproducibility Network et al., 2023).

4.2.7 Policies and procedures

Table 12: Levels of policies and procedures enablers

1: Pockets of excellence	Individuals may choose to adhere to disciplinary practices related to reproducibility.
2: Partially coordinated	Some policies and practices at faculty and/or discipline level set expectations and/or requirements for staff on reproducibility practices.
3: Organisational-level commitment	Organisational policies and procedures set expectations and/or requirements for staff, and evaluation of their efficacy occurs regularly.

There are a range of policies and procedures that can support reproducibility practices, from those that explicitly focus on this topic, to those that promote overlapping areas. Nosek identifies the open science movement as coming from a heterogeneous collection of motivations that support different parts of the research lifecycle, including open peer review, open data and code, preprints, preregistration and team science (Nosek, 2023). Consequently, implementation of relevant policies must be seen as part of the mosaic of different organisational policies, including open access, research outcomes/outputs, research data management, research ethics and integrity, diversity equity and inclusion, and hiring and promotion (Chue Hong, 2022).

Some of the practices supporting policies and procedures that can be seen utilised by teams, faculties and/or across disciplines, or across whole organisations to transition through levels of the framework as shown

- Aalto University, Finland: Open Science and Research Policy (Aalto University, 2023).
- Royal Holloway University of London, UK: Open Research policy (Royal Holloway University of London, 2022)
- TU Delft, Netherlands: Guidelines on Research Software: Licensing, Registration and Commercialisation (Bazuine, 2021).
- University of Exeter, UK: Attribution Policy (University of Exeter, 2023).
- University of Groningen, Netherlands: Research Data Management Policy of the Faculty of Science and Engineering (University of Groningen, 2022).
- University of Leiden, Netherlands: Open Science Policy and Guidelines (Institute of Education and Child Studies) (Bos et al., 2022).
- University of Lille, France: Roadmap for Open Science (University of Lille, 2021).
- University of Southern Denmark, Denmark: Open Science Policy (University of Southern Denmark, 2018).
- University of Stuttgart, Germany: Open Science Policy (TH Köln, 2022).

One interviewee noted that whilst policy is often considered a whole-of-organisation practice, lab level policies can also be important: **Researchers don't really commit to [high level] policy. What is seen is the lab level policies**. The interviewee suggested beginning with a focus on key researchers who are interested in best practice, and working on policy implementation in their areas. In this way best practice in policy can be expanded to their peers.

Processes support implementation of policy, e.g. provision of ethics templates, mandated study registration during protocol writing, requirements for

in table 12, include:

- Policies support reproducibility, and allow for disciplinary differences where necessary. There are many examples of relevant policies and strategies with different foci in research organisations that to can facilitate transitions through levels of the framework, such as:

data and software management plans and integrity checks during research conduct and analysis. Policy development can certainly be a complex part of culture change; with one interviewee noting that:

We want to get to the point where we are able to agree on certain policy aspects. This is not always easy because then people start feeling they are

being forced into a direction through the policy, while the support and the advancing of this support might not be in place. … they are afraid that the policy will affect how they prioritise, that they will have to work differently than they would otherwise like to.

- **Policies relating to reproducibility practices are implemented** with consideration of supporting enablers, such as education and training initiatives needed to support compliance.

- **Policy effectiveness is evaluated.** The need for evaluation of the efficacy of reproducibility policies and practices was continually reinforced in interviews. One interviewee explained that some evaluation was being done in their organisation, such as how well the open research team is doing their work and the benefit they are providing to their organisation, but that much more was needed. Evaluations can also be useful in creating policy, and one interviewee provided an example of successful convincing organisational leadership to resource reproducibility practices due to the existence of a preregistration tracker in a relevant discipline that provided institutional-level data.

- **Organisation processes enable policy change at a reasonable speed** as reproducibility practices evolve, particularly as open science practices are evolving faster than academic culture (Wildgaard & Smitt Engberg, 2023). One interviewee described how their institution had built a dashboard to track their institutional outputs for some elements of open science, such as research data sharing and code sharing (and research on what open science practices should be monitored at biomedical research institution could also add value (Cobey et al., 2023).

The existence of relevant policy in the macro-level Strategy for Researchers (HRS4R) and the DORA are also seen as relevant, with another interviewee emphasising that: These push these ideas to help individual researchers understand why they're important and what they're about.

International policies that support reproducibility within broader frames have been created by OECD and UNESCO (OECD, 2021; UNESCO, 2021); and national open science strategies also support reproducibility approaches. For example, the Council for National Open Science Coordination (CoNOSC) is a network of national open science coordinators in the UN-European region which lists at least twenty countries that have national policies supporting open science (CoNOSC, 2022).

However, organisations can go beyond development of policies and procedures to include reproducibility in their values and consequently throughout all elements of their culture. Work on research data sharing practices includes a recommendation to nurture and codify institutional data sharing values:

Institution-wide engagement with sustainable and productive data sharing is dependent on and expressed by an organisation's values. We consider an institution's organisational culture about data sharing to encompass how leaders and researchers generally interpret data sharing, how its reward systems express these attitudes, and how it treats decisions for engaging with new data sharing opportunities and best practices. (Champieux et al., 2023).

Research organisations can also consider how to enshrine these values into action, with suggestions on how universities can make research culture more open including establishing an open research working group:

The working group should have the support of the pro

landscape was identified as beneficial by a number of interviewees, as change becomes motivated by stronger forces than personal conviction. For example, one interviewee noted: There is a national institutional roadmap on open science so institutions have the support of their government. This helps a lot in implementing things in the universities. Related initiatives such as CoARA, the Human Resources

should be led by a senior open research champion. It should include representation from your university's professional services and the research community. The UK Reproducibility Network coordinates a network of open research working groups and provides guidance on how to set one up.
(Yaqoob & Darby, 2021).

The way in which goals are turned into action can also enhance acceptance. Both Champieux et al. (2023) and Yaqoob and Darby suggest publishing an open research statement, which articulates strategic objectives, expectations of researchers, link to relevant policies and practical guidance. This has additional practical benefits: "the process of developing and consulting on a statement brings an opportunity to engage the research community and secure buy-in from key stakeholders" (Yaqoob & Darby, 2021).

4.3 Case studies

Case studies of scaling up reproducibility are provided for two research institutions: TU Delft in the Netherlands, and University of Reading in the UK. Each case study details some of the organisation's history and examples of incorporation of practices against the seven enablers from the Davidson et al. taxonomy.

4.3.1 TU Delft, Netherlands

TU Delft has a long history of supporting practices relevant to reproducibility, particularly around research data and software management, within FAIR and open science agendas. Some specific examples are as follows:

1. Tools

Some examples of how digital tools have been aligned with other systems to enable best practice include integration of the organisational data repository (4TU. ResearchData). GitHub and GitLab (Clare et al., 2021). This allows researchers to easily publish and get credit for their research software and to provide management information and statistics on the number of software projects published by researchers. In 2021, TU Delft also revised the DMP template to make creation of DMPs more cost-efficient for researchers, and integrated it further with university systems such as the data storage request system and privacy register (Carrick et al., 2021).

service and dedicated tools for data management planning, and requires the finance part of university services to support this by devising strategies to deal with the economic aspects of long-term data archiving (Ahlers et al., 2020).

2. Education and training

Research data and software management led by the TU Delft Library is still engaging PhD candidates and researchers, with plans to integrate this training into the education of Master of Science and Bachelor of Science students. As early as 2019, four scaffolded modules were envisioned, with levels of increasing specificity of the content from considering data into a general context (e.g. open science) to skills that applied to a specific data type or a research discipline. This was envisioned to be a collaborative work with different internal stakeholders, and with external organisations that have already developed training material and/or courses, to ensure the sustainability of the training (Martinez-Lavanchy et al., 2019). By 2020 the TU Delft library in collaboration with the TU Delft graduate school had embedded research data management in the doctoral education programme (Clare et al., 2021).

Training has now evolved to go beyond even centralised and faculty-level requirements. For example, the TU Delft Research Data Framework Policy includes specifics such as that doctoral supervisors are responsible for:

- Supporting PhD candidates in preparation of a written data management plan for managing research outputs within the first 12 months of their PhD.
- Ensuring that PhD candidates attend relevant training on data management.
- Ensuring that PhD candidates make all data and code underlying their completed PhD theses FAIR by sharing in a research data repository, which guarantees that data will be available for at least 10

Provision of some digital tools is also supported by policy, with the TU Delft Research Data Framework Policy specifying that the ICT department is responsible for providing infrastructure to facilitate good data management and storage where possible, in addition to secure access. This policy also specifies that the library is responsible for infrastructure such as an archival

years from the end of the research project, unless there are valid reasons which make research data unsuitable for sharing (Ahlers et al., 2020).

3. Incentives

In 2018 data stewards were providing and/or facilitating on-request training and workshops on data management topics for researchers and PhD students,

with a key factor being that "**agreements are made with faculty graduate schools to allocate credit points for participation**" (Teperek, 2019). Efforts are now underway to ensure that researchers undertaking training can also receive recognition. The role of university services in supporting this initiative is also incorporated into university policy, with the human services unit of the university responsible for "Ensuring that good research data practices are recognised as part of university profiles and behaviours (Ahlers et al., 2020).

4. Modelling and mentoring

A data champions program was launched in September 2018, for researchers who voluntarily acted as local community-based advocates. In return, they were provided with opportunities to showcase their activities during meetings at the department, faculty and TU Delft level as well as at (inter)national conferences (with travel support) to offer increased impact and visibility (Teperek, 2019). In 2023 this program had grown to encompass at least 72 champions, and TU Delft continued to provide rewards, including new networks and collaborations, recognition by faculty management, upskilling opportunities, and close working relationships with faculty data stewards (TU Delft, 2023b). There is also an open science community that provides opportunities to share knowledge and experience, to collaborate with others within and beyond TU Delft, and discover new research, teaching, management and engagement practices (TU Delft, 2023a).

5. Review and feedback

One example of review and feedback is that as part of a pilot project between TU Delft and CODECHECK, researchers had the opportunity to volunteer their projects to be code checked during a hackathon in September 2023 (Sharma, 2023). This complements data checking services already offered by the organisational data repository. Consideration is also being given as to whether the skills that participants applying these tools and practices to their own research project through short assignments and active discussion, supported by members of the TU Delft Digital Competence Centre. The Open Hardware Academy is a similar 10-week program that helps participants develop their own open hardware project. Processes have also been initiated to allocate credits to PhD candidates who join these types of mentoring programs.

6. Expert involvement and advice

In 2017 TU Delft piloted a data stewardship program to provide disciplinary specific data management support to its researchers. One data steward was initially appointed at each of three faculties, with data stewards appointed at the remaining five faculties in 2018. Some of the key features of the program included that data stewards met weekly for training, information sessions, and knowledge and practice exchange, and covered topics such as FAIR principles, General Data Protection Regulation (GDPR) law, research and software reproducibility; and that a Data Stewardship Coordinator was located at the TU Delft library (Teperek, 2019). By 2020 these roles transitioned from central library funding to being supported by each faculty, increasing sustainability (Clare et al., 2021). This program has grown further to the extent that some faculties are employing more than one data steward, and research software engineers and data managers and now also being incorporated.

7. Policies and procedures

The TU Delft Strategic Framework 2018-2024, included openness as one of its major principles (TU Delft, 2018). Building on this, the TU Delft Strategic Plan Open Science 2020-2024 aims for "**a situation in which Open Science has become the default way of practising research and education**'" (Haslinger, 2019). The TU Delft Research Software Policy was also approved in 2021 (Akhmerov et al., 2021). The TU Delft Research Data Framework Policy also specifies responsibilities of

learn in this type of workshop could be embedded in other training curricula. A range of mentoring programs are also offered, including FAIR for Research Software, an active learning experience during which participants work on their research software project. The program begins with a Code Refinery workshop on tools and best practices for scientific software development. Next, during weekly 2-hour seminars, participants work on

board, to principal investigators and research staff, and faculty heads of departments and deans. University services also have specified roles to increase alignment with other units, such as providing expert contributions to policy and practical issues related to data protection, GDPR and ownership (Ahlers et al., 2020).

4.3.2 University of Reading, UK

The University of Reading has incorporated efforts to recognise and value open research for a number of years. Efforts including the Open Research Statement (University of Reading, 2018) and Statement on Responsible Metrics for Adoption (Rowlett, 2018) have supported action in a range of areas, with some specific examples highlighted as follows:

1. Tools

The Open Research Action Plan 2021-2023 includes a goal to review existing provision of repositories and evaluate alternative repository providers, which has resulted in identification of gaps and needs, and highlighting of how such efforts can be embedded in university mechanics. The Plan also include explanation about what this means in practice, which includes:

- Using digital tools to manage, document and publish the whole research process.
- Preregistering study designs.
- Developing robust, reliable and reproducible workflows.
- Developing open research software or hardware.
- Using preprints and open peer review to accelerate dissemination and increased transparency.
- Ensuring Open Access publication of research outputs.
- Data management & sharing of data, code and materials supporting research results (as required by funders) (Darby & Roesch, 2021).

2. Education and training

The Open Research Action Plan 2021-2023 includes a number of education and training aims that have been achieved, including:

- Provision of an open research introductory course to year one or two PhD students. Internal training now offered also includes ORCID Identifiers, introduction to open research, writing a DMP, and research data probation, access promotion, funding and recognition, etc. More advanced modules will be made available on a voluntary basis, which will include both self-paced and face-to-face modules.
- Delivery of Software Carpentry workshops to support research software engineering. This has included optimisation of the delivery format to suit the University of Reading community, with two hour training sessions being run over several weeks, available on a voluntary basis.

3. Incentives

The Statement on Responsible Metrics for Adoption outlines the ten principles of the Leiden Manifesto, to which the University of Reading subscribes (Rowlett, 2018). The Open Research Action Plan 2021-2023 includes goals to include open research criteria in recruitment, reward, promotion and performance assessment; and that open research culture and practice will be part of research planning at research division and individual researcher level (University of Reading, 2021). The university's working group for evaluation, rewards and promotion is now implementing a plan to lead into signing of DORA in 2025. This involves a piloting phase with the schools of psychology and law, and development of training and policy documents. For example, promotions require evidence of engagement with the university's guidance on open research (University of Reading, 2023b). Feedback is mixed, with a minority of staff arguing in favour of impact factors and research metrics.

Another relevant program is the Open Research Award (University of Reading, 2023a), which has existed since 2019,and "is a çagship in encouraging the sharing of open research experiences, building conædence and developing new skills … [to] raise the proæle of open research within the institution by demonstrating the University's commitment to it" (Sutton, 2021).

management (University of Reading, 2023). Plans for the Open Research Action Plan 2024-2027 include a change to self-paced online delivery of in-hour materials, with introductory modules on open and reproducibility research practices, and research integrity. These will become mandatory for all PhD students, and embedded in university processes for permanent members of staff, e.g. required to pass

4. Modelling and mentoring

The University of Reading has an Open Research Champion program. Champions are "a research-active member of staff or research student who volunteers a small amount of their time to help promote Open Research, provide information and support to peers and colleagues, and facilitate the adoption of open and reproducible research practices." It is planned that this

program will continue in Open Research Action Plan 2024-2027, with changes likely to ensure schools take ownership of champions embedded in their area. Other innovations may include the inclusion of responsibility for championing open research in the Research Division Lead role (which is part of the senior management team in each school).

An Open Research Forum for all members of the university also assists in achieving these goals. A small amount of funding is made available to Champions for activities such as the organisation of workshops or attendance at training courses and events, and the champions program is supported by the Research Engagement team in the Library (University of Reading, n.d.-b). Open research case studies are also used to enable researchers to "explain how they have used open practices to carry out and communicate their research, and explore the benefits and challenges of being open" (University of Reading, 2022a).

5. Review and feedback

The university has a range of initiatives that support and feedback at the general level. For example, training provided centrally by the university relates to the role of researcher as a manager, and includes training on topics such as research integrity and successful mentoring. All staff have access to at least 10 days of training, as part of their commitment to the Concordat for Researcher Development (University of Reading, 2023c). All staff can also request to be assigned a mentor or a coach, provided by the University. In 2023, the University also rolled out an ambitious programme to get every academic output reviewed before submission. Additionally, each School organises specific training and support locally, for example, on grant craftsmanship, writing support, or providing mentors for staff and early career researchers.

6. Expert involvement and advice

required to develop cross-university continuous professional development and recognised role specifications in research software engineering; training courses for researchers and PhD students (resulting in specific role definitions and career paths for research software engineers, which are incorporated with the Digital Technology Services); and activities such as coding clubs (University of Reading, 2023d).

Another outcome of the Open Research Action Plan 2021-2023 is the delivery of digital humanities support through the Digital Humanities Hub which promotes innovation through digital tools, methodologies, and engagement with developments in Digital Humanities as a field (University of Reading, n.d.-a).

7. Policies and procedures

Policies at the University of Reading include the Statement on Open Research in 2018, which was then followed by the creation in 2019 of the Committee on Open Research and Research Integrity responsible for implementing open research policies and procedures (Darby & Roesch, 2021). More detailed policies include the Research Data Management Policy which sets out the requirements that researchers and research students must observe in the management, preservation and sharing of research data (University of Reading, 2017); and a policy to develop and make research integrity training mandatory for every student and staff. This training includes aspects of open research.

One of the ways in which policy development is integrated throughout the open research culture include a policy to fund a statistical CoP (facilitated by a 0.5 FTE part-time director for 2 years) that gathers representatives of every school and functions to examine how statistics are used, is also able to propose changes to improve policy (University of Reading, 2022b). Similarly, part of the possible functions of open research champions includes to "inform University

in addition to creating a community of open research champions, the Open Research Action Plan 2021-2023 includes goals to develop a research software engineering community (University of Reading, 2021). This has resulted in RSE@UOR, and the creation of a sustainable programme of courses, tutorials, workshops and online resources; a research software engineering CoP; a plan for the structure, governance and support

strategy and service development, by advocating for the needs of their School and engaging with the Committee on Open Research and Research Integrity" (University of Reading, n.d.-b). The university's 2023 survey of all research and research enabling staff to understand the research culture is also likely to result in changes to policies and procedures that may include a restructuring of research support.

4.4 Assessment worksheet

The third and final element of the framework for scaling up reproducibility is an assessment worksheet. The aim of the assessment worksheet is to allow an organisation to assess its capability to support reproducibility practices, and act as a starting point for discussions around maintaining or improving this capability. It is based on the Digital Preservation Coalition's Rapid Assessment Model which enables an organisation to assess its digital preservation capability (Digital Preservation Coalition, 2021).

The worksheet enables an organisation (or faculty or team) to complete table 13.

This information is then utilised to create a radar chart (or spider plot) to visualise the current level of each enabler against the target level. Whilst this chart provides a high level overview as a starting point for further consideration, it is also recognised that an organisation could be simultaneously at more than one level of the framework. This could also be desirable, enabling experimentation with newly emerging best practices in pockets of excellence; and gaining traction, support and evidence of demand; before transitioning these to large-scale adoption.

The worksheet also includes the following guidelines for its usage based on feedback received in the interviews and focus groups around how to influence change within a research organisation:

1. Decisions on target levels should also include consideration of the following four areas (which are explored in detail below):

    a. Macro-level environmental factors
    b. Meso-level organisational factors
    c. Meso-level change management strategies
    d. Micro-level stakeholders

2. Interaction is needed with a number of parts of the university to assess current status. Interaction is also encouraged regarding target levels and next steps, i.e. to use this worksheet is a conversation starter. This worksheet can be used to both identify and value practices that already exist, as well as consider future goals.

The literature review also identified research relevant to this specific type of cultural change to inform these guidelines; however, it would be noted that cultural change and/or in the research sector is a much larger topic on which a wide range of information is available.

Additional assessment tools could be used for prioritisation of practices for scaling up reproducibility. One solution is the commonly used two by two matrix shown in table 13, in which possible practices are assigned to a relevant quadrant based on their level of effort required, and level of impact that can be achieved.

Table 13: Assessment worksheet

Enablers	Current level	Why did you select this level?	Target Level (optional)	What needs to be in place to get there?
A. Tools	1/2/3			
B. Education and training	1/2/3			

C. Incentives	1/2/3
D. Modelling and mentoring	1/2/3
E. Review and feedback	1/2/3
F. Expert involvement and advice	1/2/3
G. Policies and procedures	1/2/3

Table 14: Impact and effort matrix

	Low impact	High impact
Low effort	Slow change	Quick wins
High effort	Difficult roads	Major projects

This approach shown in table 14 is used in making recommendations on empowering ECRs to improve research culture and practice. For example, low level effort and high impact activities include starting a departmental journal club (Kent et al., 2022). In a similar vein, the European Commission Directorate General for Research and Innovation et al. (2022) suggests identifying any new measures which do not add administrative burden to projects.

A more advanced solution is the research improvement cube, where proposed interventions can be mapped in three dimensional space according to cost, potential benefits and the certainty in these estimates: "Where there is certainty, implementation decisions can be informed by institutional prioritisation, but where there is uncertainty, options include implementation with audit (where costs are low) or randomised studies" (Macleod & the University of Edinburgh Research Strategy Group, 2022). In a similar vein, Davidson et al. concluded that:

Given most interventions outlined in the taxonomy have not been evaluated for their impact on research quality and reproducibility, there is a clear need for more institutional interventions [to] be evaluated. Priority areas for evaluation should be those currently in common use at institutions, to assess their value. Implementation of new or different interventions could be those that are no- or low-cost, such as open access tools and software to enhance research practices.

(Davidson et al, 2022).

The assessment worksheet is also complemented by guidelines for usage. Whilst much of this study focused explicitly on practices to scale up reproducibility, the research also considered the broader question of how to support scaling up with the context of a research organisation. This recognises that meso-level cultural

changes require consideration of other factors at macro, meso and micro-levels, as detailed in the Knowledge Exchange Open Science Framework.

4.4.1. Guidelines: Macro-level environmental factors

Macro-level environmental factors were consistently identified in this study as relevant to research organisation-level changes. As defined in section two, macro refers to the system as a whole, e.g. a government, national/regional funder, or general regulatory framework (Neylon et al., 2019). Whilst funder and publisher mandates were highlighted as relevant drivers, the key macro-level factors that research organisations should consider relate to national policy, research on efficacy of reproducibility practices, and broader changes to the research ecosystem.

National policy

Study participants identified situations where the existence of national-level policy or strategies related to reproducibility, or lack thereof, affected the motivation of research organisations, and sometimes their capability (for example, where national training communities or initiatives exist to support local instances). Consequently, research organisations utilising the framework should consider what does or does not exist in their own environment, which may help or hinder their cause. For example, one interview noted: Horizon Europe has huge requirements around research data management so it's possible to interpret these as including reproducibility as a parameter. So it's possible to see them as endorsing it, although they don't mention it explicitly.

Research on the efficacy of reproducibility practices

A repeated theme in this study was the need for more research on the efficacy of reproducibility practices, to ensure that those being scaled up have maximal impact. Many studies note the need for research of the effectiveness of interventions to improve research

good thing", we do not know by how much it might improve performance or what the costs might be. In such circumstances, testing interventions in randomised trials may be helpful.
(Macleod & the University of Edinburgh Research Strategy Group, 2022).

Broader changes to the research ecosystem:
Organisations should consider international and national discussion on relevant issues, such as technological advances and research assessment reform:

- Technological advances: In general, technologies such as generative AI may support the importance of reproducible research, as the potential for reuse of the research continues to increase. Generative AI may be able to be used to reduce workloads and/or enable scaling up. For example, it could be used in writing parts of DMPs; for checking computational parts of a research paper; to evaluate assignments in reproducibility training; or to enable an evaluator to check work in a different computer language to their own expertise, reducing the number of evaluators required.
- Research assessment reform: Broader discussions on this topic will influence reproducibility agendas in systematic ways. For example, one research participant highlighted that the Research Excellence Framework (REF) in the UK now recognises research enabling staff rather than technicians (to enable inclusion of librarians).

4.4.2. Guidelines: Meso-level organisational factors

Any consideration by a research organisation in scaling up reproducibility should consider a range of institutional factors, including vision, strategy and culture; and structure, operations and resources.

Organisational vision, strategy and culture

The broader environment within which reproducibility is situated within the organisation must be considered

reproducibility (Macleod & the University of Edinburgh Research Strategy Group, 2022).

Institutions seeking to implement change will wish to have confidence that that change will be effective, and will provide good value. Taking for example the provision of enhanced statistical and methodological support, while there is some consensus that this would be "a

which setting goals for scaling up. For example, Davidson et al. (2022) emphasise that "the implementation and evaluation of interventions outlined in this study's taxonomy should be considered along with the institution's current culture and potential shifts that could be made to encourage and promote open science practices"; and encourages institutions to examine their research culture and how it may or may not be

supportive of producing robust and credible research. As one interviewee noted: **You must understand local culture to find the best way to implement this practice so change that works for that culture, not against the culture.** Consideration of these factors can also be applicable at smaller levels, such as teams (Rolland et al, 2020).

The organisational appetite for risk should also be considered, as the risks of action should be weighed against the risks of inaction. As one interviewee noted:

A big problem with scalability in reproducibility is the curation aspect. There's a risk if you scale up very efficiently, that you waste a lot of time reproducing things which have no place being reproduced. So being super effective in reproducing experiments is good up to a point. But we still need to make decisions at a community level on what should be reproduced and what should not.

A number of reasons were identified why scaling up reproducibility practices could be counter-productive:

- The limited evaluation of the benefits of reproducibility practices makes it difficult to be confident that the practices will increase reproducibility of research.
- If reproducibility becomes a requirement then it is no longer undertaken because researchers have personally understood the benefits of doing so.
- Policies affect how people prioritise and can change their work practices in positive and/or negative ways.

Organisational structure, operations and resources
Relevant factors in this category include the university's breadth of disciplines, size, processes and budgets. It is well recognised that different research disciplines may engage with reproducibility differently, and that some disciplines are more advanced in their integration than others. As this study's assessment worksheet suggests, assessment should lead to action. Yaqoob and Darby's

Similarly, any strategy for scaling up reproducibility must be nuanced to account for differences, particularly disciplinary: **"For some epistemic cultures, reproducibility will be harder to understand and implement, or perhaps is not even the goal; in others, reproducibility may not be seen as the key quality hallmark, but just as an option among many"** (Chiarelli et al., 2021). This can be nuanced further, that **"more understanding on the meanings and implications of reproducibility across disciplines is needed to provide the evidence to underpin such flexibility"** (European Commission Directorate General for Research and Innovation. et al., 2022).

Other factors are also relevant, with a conference on reproducibility identifying the overarching message to be that:

… multiple approaches are both necessary to address the complexities of implementing reproducible research and welcomed by researchers, who span disciplines and career stages and are therefore not a monolithic group with identical motivations and needs. Whereas top-down policy changes may be effective to spur institutions and principal investigators to make major, potentially costly changes, bottom-up approaches can engage those who are more curious and flexible in making incremental changes to their practices—and who may band together to shift norms through collective efforts. (Rethlefsen et al., 2022).

On a similar note, the University of Reading's Open Research Action Plan 2021-2023 notes that implementation should: **"Not be fully prescriptive from the outset, allowing responsiveness to progress, new ideas and needs expressed by each School (noting that the state of readiness varies between disciplines) and Function, and a changing landscape"** (University of Reading, 2021). One interviewee highlighted that their organisation had created personas for the different

suggestions on how universities can make research culture more open include creating an action plan that includes measurable objectives to be achieved over a defined period, to "give strategic direction to institutional effort. It can be a vehicle for securing engagement with open research objectives, bringing stakeholders and activities into strategic alignment, and obtaining resource to support activities" (Yaqoob & Darby, 2021).

members of the research community, identifying differences in their research practices, and consequently what kind of support and infrastructure is relevant to them.

Resourcing is also key, with a study assessing the reproducibility of research results in European Union Framework Programmes for research finding that researchers "estimated the need to dedicate an average

of 17% of their budgets to reproducibility-related costs" and reported a 4% budget increase: "The survey results also indicate that projects with a lower budget tend to spend a bigger budget share on reproducibility. This suggests that there are economies of scale in reproducibility, which will negatively impact smaller projects, which may require additional support" (European Commission Directorate General for Research and Innovation et al., 2022).

4.4.3. Guidelines: Meso-level change management strategies

The research for this study generated significant discussion on the need to understand how to enable change within research organisations, to ensure that discussions on scaling up reproducibility practices achieve results. This should be framed within an understanding of each organisation's uniqueness: As stated by Drude et al.:

There is no one-size-atts-all approach for improving the practice and culture of research". Factors that support creation of tailored results for stakeholders in reproducible research include "support of key decision makers, managing expectations, employment of expertise, a successful communication strategy, identifying important incentives, stakeholder engagement, and united bottom-up and top-down approaches. (Drude et al., 2022).

Use of change strategies

Emphasis was also seen on the need to understand how to successfully implement change: "The measures we outline here will not transform things overnight, but ongoing strategic action by institutions can gradually bring about the change in research culture that will drive up quality, integrity and reuse" (Yaqoob & Darby, 2021). The use of pilots was often emphasised (for example, see European Commission Directorate General for Research and Innovation. et al., 2022), with one introduction of a pilot for spot checking of reproducibility involves a careful lead-in to support acceptance of this process, including an initial working paper for senior staff, a planned pilot to demonstrate the potential benefits, and provision of appropriate training and support for researchers and research-adjacent support staff. The training opportunities were part of a carefully built program over the previous two years to gradually provide reproducibility courses at a range of levels. Kohrs et al. also provides tips for all their strategies, including to be persistent and anticipate resistance (Kohrs et al., 20230).

There can also be benefits in slow change from a diversity, equity and inclusivity viewpoint, particularly for marginalised communities. For example, Haselmayer argues against short-term interventions and fixes and for a 'slow lane' process of building trust and capabilities at the local level (Haselmayer, 2023). There are many change management strategies that can be utilised to facilitate these outcomes, including transition management, which "involves a cyclical process of phases at various scale levels: stimulating niche development at the micro-level, aading new attractors at the macro-level by developing a sustainability vision, creating diversity by setting out experiments, and selecting successful experiments that can be scaled up" (Rotmans & Loorbach, 2009).

Benefits of consultation. A recurring theme was the need for interaction with a number of parts of the university to assess an organisation's current status, when completing the assessment worksheet. Furthermore, interaction is also encouraged regarding target levels and next steps, i.e. to use this worksheet is a conversation starter. This worksheet can be used to both identify and value practices that already exist, as well as consider future goals.

4.4.4. Guidelines: Micro-level stakeholders

interviewee explaining the benefits of seizing an opportunity: We saw that some departments already had some kind of programming courses in their curriculum, so we talked to them … and asked them, should we do this for everyone? So it's useful to experiment to see how big the traction is.

For example, the University of Exeter's potential

benefits from the involvement of leadership; however, individual researchers remain important both in their own environments, and potentially as change agents in larger spheres. With regard to the former, Chiarelli et al. (2021) note: "Individual researchers and research groups have an important role to play, because they are responsible for designing, delivering and disseminating

research and are the only ones with easy access to all the research objects involved".

The role of individual staff in the change process: Individual staff are a key part of the change process, and the importance of personal drive cannot be overvalued. Many interviewees were clearly intrinsically motivated: I started reproducibility practices as a personal thing. I strongly support the teaching of ethics and one side of that is research integrity and conduct of research. It isn't responsible conduct of research if it isn't reproducible. Many interviewees also provided feedback on the trade-offs at the personal level of supporting reproducibility - and why they still decided to focus on reproducibility:

At the moment open science comes at the cost of producing less publications. I could have been publishing instead of creating open science infrastructure, and that probably cost me some grants as I may not have had enough publications. So it's about finding your own way – are you passionate enough about it despite some drawbacks?

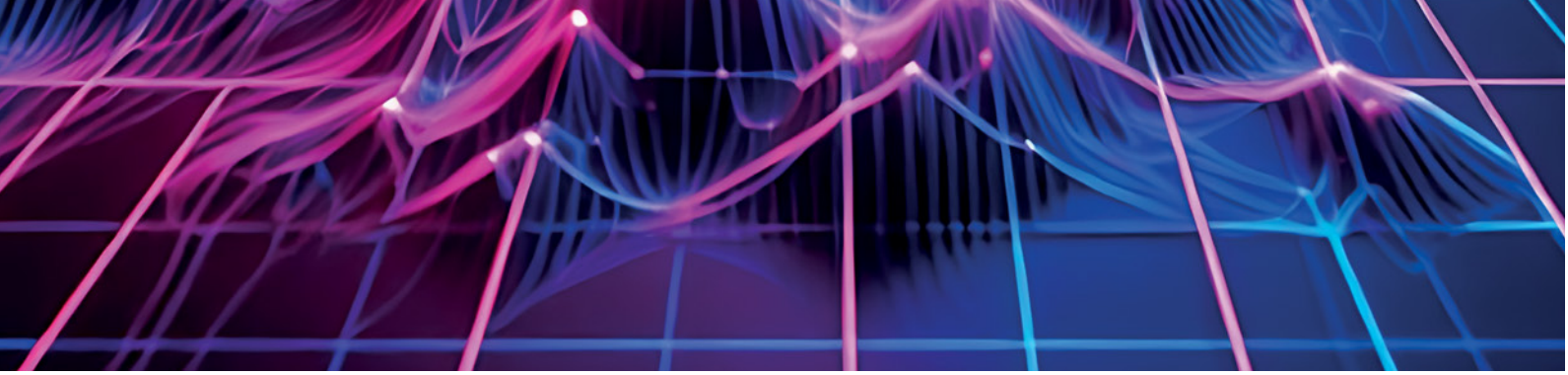
It was a personal ethical decision to practise reproducible science. I feel that becoming a scientist and contributing to science are not the same things. For example, requirements around publishing and funding can be at conflict with contributing to science, and I chose to prioritise contributing to science.

The role of individual researchers in driving change: Individuals can also play critical roles as change leaders of grassroots initiatives, or at least within their own teams. ECRs are also commonly recognised for their ability to see value in reproducibility-related practices and recognise its importance (Zečević et al., 2020). For example, open science practices that are suggested for novice graduate students include journal clubs, project workflow, preprints, reproducible code, data sharing,

I was introduced to open science in my PhD, as I realised many things were unclear. For example, I'd find that the sample sizes were not given in a figure, and I'd email authors to ask, but I couldn't get answers. So I was led to thinking about how to do science better, without mistakes and without losing information. I started finding others and realised there was a community of advocates for open science in my country that was well developed.

Anyone can drive change; Kohrs et al.'s tips for increasing requirements for reproducible research and open science practices includes suggestions to empower individuals, such as that if a student's institution or department does not have requirements for reproducible research and open science practices in graduate theses, then they can form their own individual agreement (Kohrs et al., 2023).

transparent writing, preregistration, and registered reports (Kathawalla et al., 2021). This importance of connecting personal motivation with a similarly motivated community was also emphasised by another interviewee:



5. Conclusion

The study originally hypothesised that the community element of Nosek's strategy for culture change would be most relevant at this stage of the diffusion of innovation curve, whilst noting that all æve elements could potentially play a role as change is not always linear. Community has certainly been identiæd as an important factor in scaling up reproducibility, with examples for most of the seven enablers including examples of internal communities, and/or national, disciplinary or international communities of relevance. However, the other four elements of Nosek's strategy are also important: policy, incentives, user interface/experience (or skills and training), and infrastructure.

Perhaps a more nuanced understanding is that community may be essential in transitioning between the period of early adopters to early majority, as per the diffusion of innovation diagram; however, the reality of the status of reproducibility is highly varied not only across the research ecosystem internationally, but also across research organisations, and even within organisations, faculties and teams.

Consequently, all five elements of the strategy for culture change remain important in a broad sense, although in some specific contexts one or more of the five may have more relevance. Similarly, all seven enablers from the Davidson et al. taxonomy are seen to be important in scaling up reproducibility, and research organisations engaging with the framework should engage across this spectrum.

A useful next step would engage the community in testing and evaluation of the framework to increase its value. Whilst this by definition involves use of the framework by individual research organisations, the recognised value of communities in sharing and extending best practice also provides a way forward. The ongoing work of both national reproducibility networks and coordination across these provide one avenue for possibly supporting this, with university consortia providing another.

This should be seen in the context of broader changes affecting the sector, in particular the availability and use of AI, which is making it harder to assess the quality of research outputs at the same time as the quantity of outputs is rapidly increasing. Nevertheless, this provides an opportunity for reproducibility practitioners to emphasise the importance of ensuring that the majority of researchers are provided with appropriate enablers and interventions.

6. References

Aalto University. (2023). **Open Science and Research Policy**. https://www.aalto.å/en/open-science-and-research/aalto-university-open-science-and-research-policy

Ahlers, I., Andrews, H., Cruz, M., van Dijck, J., Dintzner, N., Dunning, A., Eggermont, R., den Heijer, K., Ilamparuthi, S., van der Kruyk, M., van der Kuil, A., Kurapati, S., Love, J., Martinez Lavanchy, P., Plomp-Petersen, E., de Smaele, M., Teperek, M., Turkyilmaz-van der Velden, Y., Versteeg, A., & Wang, Y. (2020). **TU Delft Research Data Framework Policy**. https://doi.org/10.5281/zenodo.4088123

Akhmerov, A., Bazuine, M., Beardsell, J., van den Bogerd, R., Branchett, S., Dunning, A., Keijzer-de Ruijter, M., Cruz, M., Martinez-Lavanchy, P., Schenk, M., Spaargaren, M., & Teperek, M. (2021). **TU Delft Research Software Policy**. https://doi.org/10.5281/zenodo.4629661

Allen, K.-A., Butler-Henderson, K., Reupert, A., Longmuir, F., Finefter-Rosenbluh, I., Berger, E., Grove, C., Heffernan, A., Freeman, N., Kewelramani, S., Krebs, S., Dsouza, L., Mackie, G., Chapman, D., & Fleer, M. (2021). Work like a girl: Redressing gender inequity in academia through systemic solutions. **Journal of University Teaching and Learning Practice, 18(3), 14–29. https://doi.org/10.53761/1.18.3.3**

Alrasheedi, M., Capretz, L. F., & Raza, A. (2016). Management's Perspective on Critical Success Factors Affecting Mobile Learning in Higher Education Institutions—An Empirical Study. **Journal of Educational Computing Research**, **54**(2), 253–274. https://doi.org/10.1177/0735633115620387

Aragon, S., Antonioletti, M., Walker, J., & Chue Hong, N. (2023). Understanding the software and data used in the social sciences: A study for the Economics and Social Research Council. Zenodo. https://doi.org/10.5281/zenodo.7785707

Armeni, K., Brinkman, L., Carlsson, R., Eerland, A., Fijten, R., Fondberg, R., Heininga, V. E., Heunis, S., Koh, W. Q., Masselink, M., Moran, N., Baoill, A. Ó., Sarafoglou, A., Schettino, A., Schwamm, H., Sjoerds, Z., Teperek, M., Van Den Akker, O. R., Van'T Veer, A., & Zurita-Milla, R. (2021). Towards wide-scale adoption of open science practices: The role of open science communities. **Science and Public Policy**, **48**(5), 605–611. https://doi.org/10.1093/scipol/scab039

Barker, M., & Buchhorn, M. (2022). **Research Software Capability in Australia**. Zenodo. https://doi.org/10.5281/zenodo.6335998

Barker, M., Chue Hong, N. P., Katz, D. S., Lamprecht, A.-L., Martinez-Ortiz, C., Psomopoulos, F., Harrow, J., Castro, L. J., Gruenpeter, M., Martinez, P. A., & Honeyman, T. (2022). Introducing the FAIR Principles for research software. **Scientiæ Data**, **9**(1), 622. https://doi.org/10.1038/s41597-022-01710-x

Bazuine, M. (2021). **TU Delft Guidelines on Research Software: Licensing, Registration and Commercialisation**. https://doi.org/10.5281/zenodo.4629635

Begley, C. G., Buchan, A. M., & Dirnagl, U. (2015). Robust research: Institutions must do their part for reproducibility. Nature, 525(7567), 25–27. https://doi.org/10.1038/525025a

Biernaux, J., Grard, A., & Zahreddine, S. (2022). Joining forces: Building a community of data ambassadors across universities in Brussels-Wallonia Federation (Belgium). https://orbi.uliege.be/bitstream/2268/293219/1/Poster_AdelineGrard_LIBER_2022.pdf

Bochynska, A. (2023). **Barriers and enablers to building reproducibility communities**. https://drive.google.com/drive/folders/1IR1ciksn2cvht94ueGELsPywGOdK3wbm

Bos, P., van Geel, M., & Alink, L. (2022). **Open Science Policy and Guidelines (Institute of Education and Child Studies)**. https://www.organisatiegids.universiteitleiden.nl/binaries/content/assets/sociale-wetenschappen/pedagogische-wetenschappen/reglementen/ospolicy_iecs_1.4.pdf

Brinkman, L. (2023). **Reproducibility Networks and Open Science Communities: Drivers for change**. https://drive.google.com/drive/folders/1IR1ciksn2cvht94ueGELsPywGOdK3wbm

Carrick, R., Drafiova, M., Herterich, P., Nicholson, M., de Boom, G., Braat, A., Dunning, A., Haslinger, I., Kees den Heijer, I., Rudneva, M., Schenk, M., de Smaele, M., Teperek, M., Veloo, M., Vuik, K., & Wang, Y. (2021, February 22). **Towards better efæciency – integrating data management plans with institutional systems** [Veloo, Kees Vuik, Yan Wang]. https://openworking.wordpress.com/2021/02/22/towards-better-efåciency-integrating-data-management-plans-with-institutional-systems/

Carver, J. C., Chue Hong, N. P., & Thiruvathukal, G. K. (Eds.). (2016). **Software Engineering for Science** (0 ed.). Chapman and Hall/CRC. https://doi.org/10.1201/9781315368924

Center for Open Science. (2019). **Preregistration Challenge**. https://www.cos.io/initiatives/prereg-more-information

Chambers, C., Logan, C., Lynnot, D., Marsden, E., Morley, A., Bella, A. F., McLatchie, N., Piazza, J., Hartwright, C., & Capelier-Mourguy, A. (2023). **Recognising Open Research Practices in Hiring Policies: Modular Certiæcation Initiative**. Open Science Framework. https://osf.io/https://osf.io/qb7zm

Champieux, R., Solomonides, A., Conte, M., Rojevsky, S., Phuong, J., Dorr, D. A., Zampino, E., Wilcox, A., Carson, M. B., & Holmes, K. (2023). Ten simple rules for organizations to support research data sharing. **PLOS Computational Biology**, **19**(6), e1011136. https://doi.org/10.1371/journal.pcbi.1011136

Chiarelli, A., Loffreda, L., & Johnson, R. (2021). **The Art of Publishing Reproducible Research Outputs: Supporting emerging practices through cultural and technological innovation**. Zenodo. https://doi.org/10.5281/zenodo.5521077

Christensen-Dalsgaard, B. (2023). **Reproducibility—Thoughts on the underlying FAIR ecosystem**. https://drive.google.com/drive/folders/1IR1ciksn2cvht94ueGELsPywGOdK3wbm

Chue Hong, N. P. (2022). **Implementation of policies on research software**. https://doi.org/10.6084/m9.ågshare.21347697

Chue Hong, N. P., Katz, D. S., Barker, M., Lamprecht, A.-L., Martinez, C., Psomopoulos, F. E., Harrow, J., Castro, L. J., Gruenpeter, M., Martinez, P. A., & Honeyman, T. (2022). FAIR Principles for Research Software (FAIR4RS Principles).

Research Data Alliance. https://doi.org/10.15497/RDA00068

Claerbout, J. F., & Karrenbach, M. (1992). Electronic Documents Give Reproducible Research a New Meaning. In Seg Technical Program Expanded Abstracts (pp. 601–604). Stanford Exploration Project. https://library.seg.org/doi/book/10.1190/SEGEAB.11

Clare, C. (2019). How to build a community of Data Champions: Six Steps to Success. https://doi.org/10.5281/zenodo.3383813

Clare, C., Cryan, A., Gramsbergen, E., van der Heul, J., Martinez Lavanchy, P., Rumondor, E., de Smaele, M., Teperek, M., Wang, Y., & Zormpa, E. (2021, March 29). **What a year! Research Data Services contributions to TU Delft in 2020**. https://openworking.wordpress.com/2021/03/29/what-a-year-research-data-contributions-to-tu-delft-in-2020/

Cobey, K. D., Haustein, S., Brehaut, J., Dirnagl, U., Franzen, D. L., Hemkens, L. G., Presseau, J., Riedel, N., Strech, D., Alperin, J. P., Costas, R., Sena, E. S., van Leeuwen, T., Ardern, C. L., Bacellar, I. O. L., Camack, N., Britto Correa, M., Buccione, R., Cenci, M. S., … Moher, D. (2023). Community consensus on core open science practices to monitor in biomedicine. **PLOS Biology**, **21**(1), e3001949. https://doi.org/10.1371/journal.pbio.3001949

Committee on Developing a Toolkit for Fostering Open Science Practices: A Workshop, Board on Research Data and Information, Policy and Global Affairs, & National Academies of Sciences, Engineering, and Medicine. (2021). **Developing a Toolkit for Fostering Open Science Practices: Proceedings of a Workshop** (T. Arrison, J. Saunders, & E. Kameyama, Eds.; p. 26308). National Academies Press. https://doi.org/10.17226/26308

CoNOSC. (2022). **CoNOSC Members OS policies**. https://conosc.org/os-policies/

Darby, R., & Roesch, E. (2021). **Introducing the University's Open Research Action Plan 2021-23**. https://libguides.reading.ac.uk/ld.php?content_id=33417166

Davidson, A. R., Barbour, G., Nakagawa, S., Holcombe, A. O., Fidler, F., & Glasziou, P. P. (2022). **Taxonomy of interventions at academic institutions to improve research quality** [Preprint]. Scientific Communication and Education. https://doi.org/10.1101/2022.12.08.519666

Digital Preservation Coalition. (2021). **Rapid Assessment Model**. Digital Preservation Coalition. https://www.dpconline.org/digipres/dpc-ram

Directorate-General for Research and Innovation, Cabello Valdes, C., Rentier, B., Kaunismaa, E., Metcalfe, J., Esposito, F., McAllister, D., Maas, K., Vandevelde, K., & O'Carroll, C. (2017). **Evaluation of research careers fully acknowledging Open Science practices: Rewards, incentives and/or recognition for researchers practicing Open Science**. Publications Office of the European Union. https://data.europa.eu/doi/10.2777/75255

Drude, N., Martinez-Gamboa, L., Haven, T., Holman, C., Holst, M., Kniffert, S., McCann, S., Rackoll, T., Schulz, R., & Weschke, S. (2022). Finding the best fit for improving reproducibility: Reflections from the QUEST Center for Responsible Research. **BMC Research Notes**, **15**(1), 270. https://doi.org/10.1186/s13104-022-06108-x

European Commission. Directorate General for Research and Innovation. & EOSC Executive Board. (2020). **Six Recommendations for implementation of FAIR practice by the FAIR in practice task force of the European open science cloud FAIR working group**. Publications Office. https://data.europa.eu/doi/10.2777/986252

European Commission Directorate General for Research and Innovation, PPMI, Know Center, & Athena RC. (2022).

Assessing the reproducibility of research results in EU Framework Programmes for Research. Publications Office. https://data.europa.eu/doi/10.2777/186782

Gärtner, A., Leising, D., & Schönbrodt, F. D. (2022). **Responsible Research Assessment II: A specific proposal for hiring and promotion in psychology** [Preprint]. PsyArXiv. https://doi.org/10.31234/osf.io/5yexm

Gownaris, N. J., Vermeir, K., Bittner, M.-I., Gunawardena, L., Kaur-Ghumaan, S., Lepenies, R., Ntsefong, G. N., & Zakari, I. S. (2022). Barriers to Full Participation in the Open Science Life Cycle among Early Career Researchers. **Data Science Journal**, **21**, 2. https://doi.org/10.5334/dsj-2022-002

Gruba, P., & Turpin, A. (2023). **Establishing a Digital Research Capability Initiative**. https://osf.io/https://osf.io/qydk2

Haselmayer, S. (2023). **Going slow means changing the world at the speed of trust**. https://blogs.lse.ac.uk/impactofsocialsciences/2023/07/11/going-slow-means-changing-the-world-at-the-speed-of-trust/

Haslinger, I. M. (2019). **TU Delft Strategic Plan Open Science 2020-2024: Research and Education in the Open Era**. Delft University of Technology. https://doi.org/10.4233/UUID:F2FAFF07-408F-4CEC-BD87-0919C9E4C26F

Heise, V., Holman, C., Lo, H., Lyras, E. M., Adkins, M. C., Aquino, M. R. J., Bougioukas, K. I., Bray, K. O., Gajos, M., Guo, X., Hartling, C., Huerta-Gutierrez, R., Jindrová, M., Kenney, J. P. M., Kępińska, A. P., Kneller, L., Lopez-Rodriguez, E., Mühlensiepen, F., Richards, A., … Weissgerber, T. L. (2023). Ten simple rules for implementing open and reproducible research practices after attending a training course. **PLOS Computational Biology**, **19**(1), e1010750. https://doi.org/10.1371/journal.pcbi.1010750

Helmholtz Open Science Office. (2023). **Helmholtz Incubator Software Award**. https://os.helmholtz.de/en/open-research-software/helmholtz-incubator-software-award/

Higman, R., Teperek, M., & Kingsley, D. (2018). Creating a Community of Data Champions. **International Journal of Digital Curation**, **12**(2), 96–106. https://doi.org/10.2218/ijdc.v12i2.562

Hooft, R., Beyan, O., Chue Hong, N. P., Cozzini, S., Hoffman-Sommer, M., Lembinen, L., Marttila, J., & Teperek, M. (2020). **FAIR in practice reference list** (1.1.0) [dataset]. Zenodo. https://doi.org/10.5281/zenodo.3898673

Jetten, M., Grootveld, M., Mordant, A., Jansen, M., Bloemers, M., Miedema, M., & Gelder, C. W. G. V. (2021). **Professionalising data stewardship in the Netherlands. Competences, training and education. Dutch roadmap towards national implementation of FAIR data stewardship** (1.0). Zenodo. https://doi.org/10.5281/zenodo.4486423

JOSS. (2020). **Journal of Open Source Software**. https://joss.theoj.org

Kathawalla, U.-K., Silverstein, P., & Syed, M. (2021). Easing Into Open Science: A Guide for Graduate Students and Their Advisors. **Collabra: Psychology**, **7**(1), 18684. https://doi.org/10.1525/collabra.18684

Katz, D. S., McHenry, K., Reinking, C., & Haines, R. (2019). Research Software Development & Management in Universities: Case Studies from Manchester's RSDS Group, Illinois' NCSA, and Notre Dame's CRC. **2019 IEEE/ACM 14th International Workshop on Software Engineering for Science (SE4Science)**, 17–24. https://doi.org/10.1109/SE4Science.2019.00009

Kelson, M. (2023, April 20). **Spotchecks for reproducibility in a university setting**. https://www.youtube.com/watch?v=fnQR8NiCoR4

Kent, B. A., Holman, C., Amoako, E., Antonietti, A., Azam, J. M., Ballhausen, H., Bediako, Y., Belasen, A. M., Carneiro, C. F. D., Chen, Y.-C., Compeer, E. B., Connor, C. A. C., Crüwell, S., Debat, H., Dorris, E., Ebrahimi, H., Erlich, J. C., Fernández-Chiappe, F., Fischer, F., … Weissgerber, T. L. (2022). Recommendations for empowering early career researchers to improve research culture and practice. **PLOS Biology**, **20**(7), e3001680. https://doi.org/10.1371/journal.pbio.3001680

Knowledge Exchange. (2017). **Knowledge Exchange experts devised a framework that maps considerations for Open Scholarship across a variety of scales, phases and arenas.** https://knowledge-exchange.info/event/os-framework

Knowledge Exchange. (2022a). **Activity Outline 'Minimum conditions supporting research reproducibility'.** https://drive.google.com/åle/d/1tNHin0ZKjikbvHZ6hc3o-UGZv2eBwAxu/view

Knowledge Exchange. (2022b). **We aim to make research better and believe that reproducibility can do this. What do researchers need and how can institutional managers help? This work looks at FAIR principles and beyond.** https://www.knowledge-exchange.info/event/fair-data-and-software

Knowledge Exchange. (2023, May 11). **News—Take our survey and share your thoughts on practices that support reproducible research.** https://www.knowledge-exchange.info/news/articles/11-5-23

Kohrs, F. E., Auer, S., Bannach-Brown, A., Fiedler, S., Haven, T. L., Heise, V., Holman, C., Azevedo, F., Bernard, R., Bleier, A., Bössel, N., Cahill, B. P., Castro, L. J., Ehrenhofer, A., Eichel, K., Frank, M., Frick, C., Friese, M., Gärtner, A., … Weissgerber, T. L. (2023). **Eleven Strategies for Making Reproducible Research and Open Science Training the Norm at Research Institutions** [Preprint]. Open Science Framework. https://doi.org/10.31219/osf.io/kcvra

Liu, J., Carlson, J., Pasek, J., Puchala, B., Rao, A., & Jagadish, H. V. (2022). Promoting and Enabling Reproducible Data Science Through a Reproducibility Challenge. **Harvard Data Science Review**. https://doi.org/10.1162/99608f92.9624ea51

Macleod, M. & the University of Edinburgh Research Strategy Group. (2022). Improving the reproducibility and integrity of research: What can different stakeholders contribute? **BMC Research Notes**, **15**(1), 146. https://doi.org/10.1186/s13104-022-06030-2

Magliano, D. J., Macefield, V. G., Ellis, T. M., & Calkin, A. C. (2020). Addressing Gender Equity in Senior Leadership Roles in Translational Science. **ACS Pharmacology & Translational Science**, **3**(4), 773–779. https://doi.org/10.1021/acsptsci.0c00056

Martinez-Lavanchy, P. M., Dunning, A., Teperek, M., Will, N., Verbakel, E., & Zormpa, E. (2019). **Vision for Research Data & Software management training at TU Delft.** https://doi.org/10.5281/zenodo.3516873

McIntosh, L. D., & Hudson Vitale, C. (2023). Coordinating culture change across the research landscape. **Frontiers in Research Metrics and Analytics**, **8**, 1134082. https://doi.org/10.3389/frma.2023.1134082

Merrett, K., Mehta, M., Farran, E. K., & Darby, R. (2021). **Open Research Awards: A Primer from UKRN** [Preprint]. Open Science Framework. https://doi.org/10.31219/osf.io/kqgez

Michie, S., van Stralen, M. M., & West, R. (2011). The behaviour change wheel: A new method for characterising and designing behaviour change interventions. **Implementation Science**, **6**(1), 42. https://doi.org/10.1186/1748-5908-6-42

Munafò, M. R., Nosek, B. A., Bishop, D. V. M., Button, K. S., Chambers, C. D., Percie du Sert, N., Simonsohn, U.,

Wagenmakers, E.-J., Wars, J. J., & Ioannidis, J. P. A. (2011). A manifesto for reproducible science. **Nature Human Behaviour**, **1**(1), 0021. https://doi.org/10.1038/s41562-016-0021

Murphy, J., Mesquida, C., & Warne, J. P. (2022). **A Survey on the Attitudes Towards and Perception of Reproducibility and Replicability in Sports and Exercise Science**. https://doi.org/10.51224/SRXIV.234

Netherlands eScience Center. (2023a). **Research Software Engineer at the Netherlands eScience Center: Job Description** (2.0). Zenodo. https://doi.org/10.5281/zenodo.7805869

Netherlands eScience Center. (2023b). **What is a Research Software Engineer? A deaaition by the Netherlands eScience Center** (1.0). Zenodo. https://doi.org/10.5281/zenodo.7994285

Neylon, C., Belsø, R., Bijsterbosch, M., Cordewener, B., Foncel, J., Friesike, S., Fyfe, A., Jacobs, N., Katerbow, M., Laakso, M., & Sesink, L. (2019). **Open Scholarship and the need for collective action**. Zenodo. https://doi.org/10.5281/zenodo.3454688

Nosek, B. A. (2019). **Strategy for Culture Change**. https://www.cos.io/blog/strategy-for-culture-change

Nosek, B. A. (2023). **Starting, scaling, and sustaining improvements to research credibility and trustworthiness**. https://www.youtube.com/watch?v=Pn0IBuXgn5Q

Nosek, B. A., Hardwicke, T. E., Moshontz, H., Allard, A., Corker, K. S., Dreber, A., Fidler, F., Hilgard, J., Kline Struhl, M., Nuijten, M. B., Rohrer, J. M., Romero, F., Scheel, A. M., Scherer, L. D., Schönbrodt, F. D., & Vazire, S. (2022). Replicability, Robustness, and Reproducibility in Psychological Science. **Annual Review of Psychology**, **73**(1), 719–748. https://doi.org/10.1146/annurev-psych-020821-114157

Nüst, S. E. & D. (2023). **About**. CODECHECK. https://codecheck.org.uk/project/

OECD, (2020). Building digital workforce capacity and skills for data-intensive science. (OECD Science, Technology and Industry Policy Papers, Vol. 90). https://doi.org/10.1787/e08aa3bb-en

OECD. (2021). **Recommendation of the Council concerning Access to Research Data from Public Funding**. https://legalinstruments.oecd.org/en/instruments/OECD-LEGAL-0347

Omarli, S. (2017). Which Factors have an Impact on Managerial Decision-Making Process? An Integrated Framework. In.: **Essays in Economics and Business Studies. ISBN 978-80-89691-42-5**. International Research Institute s.r.o. https://doi.org/10.18427/IRI-2017-0068

ReproducibiliTea. (2023). **Welcome to ReproducibiliTea**. https://reproducibilitea.org/

ReproHack. (2023). **Welcome to the ReproHack Hub**. https://www.reprohack.org/

Responsible Metrics Champions Group. (n.d.). **Responsible Metrics Guiding Principles**. https://www.exeter.ac.uk/media/universityofexeter/research/researchservicesrebuild/Responsible_Metrics_Guiding_Principles_1.0.pdf

Rethlefsen, M. L., Norton, H. F., Meyer, S. L., MacWilkinson, K. A., Smith, P. L., & Ye, H. (2022). Interdisciplinary Approaches and Strategies from Research Reproducibility 2020: Educating for Reproducibility. **Journal of Statistics and Data Science Education**, **30**(3), 219–227. https://doi.org/10.1080/26939169.2022.2104767

Roesch, E. B. (2023, August 24). **UKRN & the UKRN Open Research Programme**. https://drive.google.com/drive/fol

Rogers, E. M. (2003). **Diffusion of Innovations** (5th ed.). Free Press.

Rolland, B., Burnside, E. S., Voils, C. I., Shah, M. N., & Brasier, A. R. (2021). Enhancing reproducibility using interprofessional team best practices. **Journal of Clinical and Translational Science**, **5**(1), e20. https://doi.org/10.1017/cts.2020.512

Rotmans, J., & Loorbach, D. (2009). Complexity and Transition Management. **Journal of Industrial Ecology**, **13**(2), 184–196. https://doi.org/10.1111/j.1530-9290.2009.00116.x

Rowlett, K. (2018) Responsible metrics: Statement on responsible metrics for adoption by the University of Reading. https://www.reading.ac.uk/discover/-/media/discover/åles/pdfs/8a75584ea8e84c63a0d4c21a34958811.pdf

Royal Holloway University of London. (2022). **Statement on Open Research**. https://royalholloway.ac.uk/research-and-teaching/research/research-environment/research-integrity/open-research/

Samota, E. K., & Davey, R. P. (2021). Knowledge and Attitudes Among Life Scientists Toward Reproducibility Within Journal Articles: A Research Survey. **Frontiers in Research Metrics and Analytics**, **6**, 678554. https://doi.org/10.3389/frma.2021.678554

Savage, J. L., & Cadwallader, L. (2019). Establishing, Developing, and Sustaining a Community of Data Champions. **Data Science Journal**, **18**, 23. https://doi.org/10.5334/dsj-2019-023

Schoots, F. (2023, August 10). **Building capacity for data stewardship in the Netherlands: Formal job proåles, training and career perspective**. https://tdcc.nl/building-capacity-for-data-stewardship-in-the-netherlands-formal-job-proåles-training-and-career-perspective/

Schoots, F., Gelder, C. van, Hoen, P.-B. 't, Mattiszik, R., Mordant, A., Wang, Y., Jonge, H. de, & Jetten, M. (2023). **Report and slide deck Workshop Data Stewards Job Proåles: Build and Sustain Capacity for FAIR Implementation, Utrecht, 4 April 2023**. https://doi.org/10.5281/zenodo.8135134

SCVO. (2023). **Digital Checkup**. https://digital.checkup.scot/

Sharma, Saba (2023). **CODECHECK and TU Delft Hackathon**. https://openpublishing.tudl.tudelft.nl/codecheck-and-tu-delft-hackathon/

Stewart, S. L. K., Pennington, C. R., da Silva, G. R., Ballou, N., Butler, J., Dienes, Z., Jay, C., Rossit, S., Samara, A., & U. K. Reproducibility Network (UKRN) Local Network Leads. (2022). Reforms to improve reproducibility and quality must be coordinated across the research ecosystem: The view from the UKRN Local Network Leads. **BMC Research Notes**, **15**(1), 58. https://doi.org/10.1186/s13104-022-05949-w

Sutton, A. (2021, July 27). **Reçecting on the Open Research Award at the University of Reading – UKCORR**. https://www.ukcorr.org/2021/07/27/reæcting-on-the-open-research-award-at-the-university-of-reading/

Swiss RN. (2023, October 25). **Swiss Reproducibility Award 2024**. http://www.swissrn.org/news/swissreproducibilityaward2024/

Teperek, M. (2019). **Data Stewardship at TU Delft – 2018 Report**. https://openworking.wordpress.com/2019/01/23/data-stewardship-at-tu-delft-2018-report/

TH Köln. (2022). **Open Science Policy**. https://www.th-koeln.de/mam/bilder/forschung/open_science_policy_en.pdf

The Carpentries. (2023). **About Us**. The Carpentries. https://carpentries.org/about/

TU Delft. (2018). **Impact for a better society: TU Delft Strategic Framework 2018-2024**. https://www.tudelft.nl/en/about-tu-delft/strategy/tu-delft-strategic-framework-2018-2024

TU Delft. (2023a). **Join the Open Science Community Delft**. https://osc-delft.github.io/join

TU Delft. (2023b). **OSC Delft Initiatives**. https://osc-delft.github.io/initiatives#data-champions

Turing Way. (2023). **Fireside Chat | Implementing open science at scale**. https://www.youtube.com/watch?v=8MnYZpwzpfU

Turing Way Community. (n.d.). Barriers to reproducibility. In **The Turing Way**. https://the-turing-way.netlify.app/reproducible-research/overview/overview-barriers.html

Turner, S., D'Lima, D., Hudson, E., Morris, S., Sheringham, J., Swart, N., & Fulop, N. J. (2017). Evidence use in decision-making on introducing innovations: A systematic scoping review with stakeholder feedback. **Implementation Science**, **12**(1), 145. https://doi.org/10.1186/s13012-017-0669-6

UK Reproducibility Network, Roesch, E. B., Pennington, C. R., Zou, Y., Fortunato, L., Dienes, Z., & DeBruine, L. (2023). **Terms of Reference, Version 4.3**. https://doi.org/10.17605/OSF.IO/X8J9Q

UK Reproducibility Network Steering Committee. (2021). From grassroots to global: A blueprint for building a reproducibility network. **PLOS Biology**, **19**(11), e3001461. https://doi.org/10.1371/journal.pbio.3001461

UKRN. (2023a). **International Networks**. https://www.ukrn.org/international-networks/

UKRN. (2023b). Open and Responsible Researcher Reward and Recognition (OR4) Project. https://www.ukrn.org/or4/

UNESCO. (2021). **Recommendation on Open Science**. https://unesdoc.unesco.org/ark:/48223/pf0000378381.locale=en

UNESCO. (2022). **Checklist for universities on implementing the UNESCO Recommendation on Open Science—UNESCO Digital Library**. https://unesdoc.unesco.org/ark:/48223/pf0000383328

University of Exeter. (2023). **Attribution Policy**. https://www.exeter.ac.uk/media/universityofexeter/governanceandcompliance/researchethicsandgovernance/202310_University_of_Exeter_Attribution_Policy.pdf

University of Groningen. (2022). **Research Data Management Policy of the Faculty of Science and Engineering**. https://www.rug.nl/digital-competence-centre/rdmpolicy-fse-2023.pdf

University of Lille. (2021). **Roadmap for Open Science of University of Lille**. https://scd.univ-lille.fr/åleadmin/user_upload/sites_services/scd/pdf/FeuillederouteSO/EN-FdRouteSO_A4pweb.pdf

University of Reading. (n.d.-a). **Digital Humanities Hub**. https://research.reading.ac.uk/digitalhumanities/

University of Reading. (n.d.-b). **What is an Open Research Champion?** https://research.reading.ac.uk/open-research-champions/about/

University of Reading. (2017). **Research Data Management Policy**. https://www.reading.ac.uk/research-services/-/media/project/functions/research-and-enterprise-services/documents/rdm-policy-1-1.pdf?la=en&hash=8D8A8AECEFF06C4F242A688833D43C83

University of Reading. (2021). **Open Research Action Plan 2021-23**. https://static.reading.ac.uk/content/PDFs/åles/Researchsupport/open-research-action-plan-2020.pdf

University of Reading. (2022a). **NEWS – Dr. Daisy Powell (Associate Professor in the Psychology of Written Language, University of Reading's Institute of Education) appointed as director of the University of Reading's new Statistics Community of Practice**. https://research.reading.ac.uk/education/2023/01/10/news-dr-daisy-powell-associate-professor-in-the-psychology-of-written-language-university-of-readings-institute-of-education-appointed-as-director-of-the-university-of-reading/

University of Reading. (2022b). **Open Research Case Studies**. https://www.reading.ac.uk/research/research-environment/open-research/open-research-case-studies

University of Reading. (2023a). 2023 Research Awards. **Engagement and Impact**. https://research.reading.ac.uk/engagement-and-impact/2023-research-awards/

University of Reading. (2023b). **Academic Promotions**. https://www.reading.ac.uk/human-resources/Working Life/Reward and recognition/Academic promotions

University of Reading. (2023c). Annual Report for the Concordat to Support the Career Development of Researchers. https://static.reading.ac.uk/content/PDFs/åles/ResearchGovernance/UUK-Annual-report-Final-Aug-23.pdf

University of Reading. (2023d). **RSE@UOR Home Page—Research Software Engineering at the University of Reading**. https://research.reading.ac.uk/rse/

University of Reading (2018). University of Reading Statement on Open Research. https://www.reading.ac.uk/discover/-/media/discover/åles/pdfs/a0cd20a0f1864bf5bfa523be98e09b9f.pdf

University of Reading. (2023d). **Training**. Opening Research at Reading Blog (ORRB). https://blogs.reading.ac.uk/open-research/training/

University of Southern Denmark. (2018). **Open Science Policy**. https://www.sdu.dk/Flexpaper/aspnet/Flex_document.aspx?doc=/sitecore/media%20library/Files/epage/Bibliotek/bib%20pdf/SDU%20Open%20Science%20Policy-09032018pdf?sc_database=web

Vienna University Library. (2023). **Data Steward**. https://www.postgraduatecenter.at/en/programs/communication-media/data-steward/

Weiner, J. (2023, June 22). **The Netherlands eScience Center Releases Job Proæle and Role Description for Research Software Engineers**. https://www.esciencecenter.nl/news/the-netherlands-escience-center-releases-job-proåle-and-role-description-for-research-software-engineers/

Wildgaard, L., & Smitt Engberg, K. (2023). **Supporting Open Science and Reproducibility at Research Support**

Wilson, G., Aruliah, D. A., Brown, C. T., Chue Hong, N. P., Davis, M., Guy, R. T., Haddock, S. H. D., Huff, K. D., Mitchell, I. M., Plumbley, M. D., Waugh, B., White, E. P., & Wilson, P. (2014). Best Practices for Scientific Computing. PLoS Biology, 12(1), e1001745. https://doi.org/10.1371/journal.pbio.1001745

Yaqoob, P., & Darby, R. (2021, September 17). Eight ways your university can make research culture more open. Times Higher Education. https://www.timeshighereducation.com/campus/eight-ways-your-university-can-make-research-culture-more-open

Appendices

Appendix A: Author profiles

Zečević, K., Houghton, C., Noone, C., Lee, H., Matvienko-Sikar, K., & Toomey, E. (2020). Exploring factors that influence the practice of Open Science by early career health researchers: A mixed methods study. HRB Open Research, 3, 56. https://doi.org/10.12688/hrbopenres.13119.2

Dr Michelle Barker is Director of the Research Software Alliance. She has extensive expertise in open science, research software, digital workforce capability and digital research infrastructure. As a sociologist, Michelle is passionate about building collaborative partnerships to achieve system change. She is a member of the FAIR Impact high level advisory committee; a Research Data Alliance Organisational Advisory Board member; chaired the OECD Expert Group on digital skills for the research sector; co-edited the European Open Science Cloud report, Digital Skills for FAIR and Open Science; and is a former Director of the Australian Research Data Commons.

Professor Neil Chue Hong is Professor of Research Software Policy and Practice at the University of Edinburgh and Director of the Software Sustainability Institute. He works to enable research software users and developers to drive the continued improvement and impact of research software and has contributed to international policy including for the OECD, the National Information Standards Organisation (NISO), and UNESCO. He is the Editor-in-Chief for the Journal of Open Research Software, co-editor of Software Engineering for Science, co-lead author of the FAIR Principles for Research Software, co-author of Best Practices for Scientific Computing, and a Fellow of the British Computer Society (Carver et al., 2016; Chue Hong et al., 2022; Wilson et al., 2014). He also leads the

- A seven month project funded by UKRI to investigate software and skills for research computing in the UK, using a mixed methods approach combining interviews, 400 survey participants and focus groups; the report will be published in 2023.
- An OECD Expert Group (chaired by Michelle Barker) to produce the report, Building digital workforce capacity and skills for data-intensive science, which made recommendations to stakeholders at multiple levels (OECD, 2020).
- Leadership of the development of the FAIR Principles for Research Software, a two year community effort involving over 500 contributors (Barker et al., 2022; Chue Hong et al., 2022).

Additionally, Neil Chue Hong led a six month project to identify the data and software being used by social sciences researchers in the UK, through survey and interviews (Aragon et al., 2023). He has contributed the software section to the recent UK particle physics technology R&D roadmap which involved interviews with 20 key stakeholders, and a community survey and the European Open Science Cloud report, Recommendations for FAIR Practice, involving a comprehensive literature survey and analysis of 86 outputs relating to the implementing of FAIR (European Commission. Directorate General for Research and Innovation. & EOSC Executive Board, 2020; Hooft et al., 2020) .

Michelle Barker also led the production of a report assessing research software capability in Australia, analysing the results of a 2021 survey from institutional representatives and individual researchers and contextualising it within the international landscape

software metrics activities within the FAIR Impact project.

Neil Chue Hong and Michelle Barker have extensive experience of using survey and interview based techniques to investigate attitudes towards research software and FAIR. They have collaborated on projects including:

(Barker & Bachmann, 2022).

Appendix B: Survey consent form and questions

Practices that support scaling of research reproducibility in organisations

Welcome to this survey on practices that support scaling of research reproducibility. This research is being conducted by Dr Michelle Barker and Prof. Neil Chue Hong on behalf of the Knowledge Exchange, to expand Knowledge Exchange work on Open Science on how the practice of conducting research in a reproducible way can be scaled up from pioneers to the majority of researchers and research support staff. This research aims to understand what types of practices assist individual researchers, research support staff, and managers to scale up practices that improve research reproducibility.

This survey should take approximately 10-15 minutes to complete. A public report will be disseminated upon completion of this work in early 2024, to provide recommendations on the minimum conditions to support research reproducibility.

This study follows the guidance on research ethics and integrity provided by the UK Research Integrity Office, and the work is overseen by the Knowledge Exchange office. Please take time to read the following information carefully and keep it for your records.

Who is eligible to take part in this study?

This survey focuses on researchers, research support staff, and managers in European research performing organisations (e.g. universities and research laboratories) The survey is aimed at personnel whose role potentially includes the practice and/or support of research reproducibility in any of the following categories:

- Researchers and/or research support staff, e.g. Research Assistant, PhD student, Postdoctoral Research Fellow, Senior Lecturer, Professors, Data Stewards, Research Software Engineer, Data Librarian, Technician, Research Officer, Data Scientist, Academic Librarian, etc.
- Managers of academic/research areas, e.g. Dean, Head of Department, Head of Centre, Group Leaders, etc.
- Managers of research support/infrastructure areas, e.g. Senior Librarian, Data Steward Group Leader, Manager/ Director/Group Leader of areas such as IT Services, Technology Transfer Office, Research Office, Library Services, Research Computing, etc.

If you have multiple roles you can complete the survey for each role (for example, once as a researcher and once as a manager). The survey is aimed at personnel with a variety of attitudes to reproducibility, ranging from those who already implement reproducibility practices and/or encourage others to do so, to those who have a more cautious approach to reproducibility.

Taking part in the study, risks and benefits

If you decide to take part in this study you will be answering questions regarding yourself and your career, any reproducibility practices that you engage with and/or support, or would like to have available in your organisational environment.

On completion of the survey, you may choose to provide your name and email. These are only needed if you agree for us to contact you for a possible follow-up interview (in which case your name would also be useful so we know how to address you, otherwise you do not need to fill in this box at the end).

Participation in this survey is entirely up to you. You can withdraw from the survey at any time, without giving a reason. Your rights will not be affected. You may withdraw or correct your data at any point in time until the publishing of the results of the study, by contacting us with the unique identifier provided on completion of the survey. If you choose to provide your name and email, you can withdraw your consent (to contact you for a follow-up interview) at any time by contacting the lead researchers, Dr Michelle Barker and Prof. Neil Chue Hong. Otherwise, this data will be kept until the completion of the study and then destroyed.

There are no significant risks associated with participation in this study.

What will happen to the results of this study?

A report and anonymised datasets will be published as research outputs. Where a low number of participants in a category might allow identification even after replacement of easily attributable identifiers, only aggregate data will be published. With your consent, information can also be used for future research. The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will be anonymised: any information that could, in the researchers' assessment, allow anyone to identify you, will be removed.

Data protection and confidentiality

Your data will be processed in accordance with the United Kingdom General Data Protection Regulation. All personal information collected about you will be kept strictly confidential, including any names or emails supplied for follow-up work. Personal data will be deleted at the completion of this study and will only be accessible to the lead researchers. Your data will be referred to by a unique participant number rather than by name, and only anonymised data will be shared with the partners of the Knowledge Exchange network. All electronic data will be stored within the European Economic Area and United Kingdom, or only transferred outside this region as encrypted files to computers secured with passwords and disks encrypted with the default operating system functionality for the sole purpose of processing by Dr Michelle Barker, who is based in Australia.

Who can I contact?

If you have any further questions about the study or require any assistance whilst completing this survey then please contact the lead researchers, Dr Michelle Barker, michelle.barker1@my.jcu.edu.au, and Prof. Neil Chue Hong, n.chuehong@software.ac.uk. If you wish to make a complaint about the study, please contact Georgia Hemings from the Knowledge Exchange, Georgia.Hemings@jisc.ac.uk. .

And thank you for your help by filling out this survey! Your contribution is greatly appreciated.

There are 25 questions in this survey.

Consent

- By proceeding with the survey, I agree to all of the following statements:
- I have read and understood the above information.
- I understand that my participation is voluntary, and I can withdraw at any time.
- I consent to my anonymised data being used in academic publications and presentations.
- I consent to my anonymised data being used in future research.
- I consent to my anonymised data being shared with the partners in the Knowledge Exchange network.
- I consent to the results of the study being shared and published as research outputs.

Question 1: (Mandatory) I consent to all of the above.
Please choose only one of the following:
- Yes
- No

You and your career

Question 2: (Mandatory) Are you answering this survey in your role as a:
Please choose only one of the following:

- Researcher and/or research support staff, e.g. Research Assistant, PhD student, Postdoctoral Research Fellow, Senior Lecturer, Professors, Data Stewards, Research Software Engineer, Data Librarian, Technician, Research Officer, Data Scientist, Academic Librarian, etc.
- Manager in an academic/research setting, e.g. Dean, Head of Department, etc.
- Manager in a support/infrastructure setting, e.g. Senior Librarian, Data Steward Group Leader, Manager/Director/ Group Leader of areas such as IT Services, Technology Transfer Office, Research Office, Library Services, Research Computing, etc.

Question 3: Which type of organisation do you work for? If you are answering this survey as a researcher then please answer in terms of the environment in which the majority of your reproducibility focus takes place.
Choose one of the following answers

Please choose only one of the following:

- Higher Education Institution (e.g. university)
- Research Institute (e.g. national laboratory)
- Disciplinary Research Consortium (cross-organisational collaboration on a particular research topic)
- Research Funding Organisation
- Other

Question 4: What is the geographic scope of the organisation that you work for? (If you work across multiple countries, please choose Other and explain below)

Choose one of the following answers. If you choose 'Other:' please also specify your choice in the accompanying text field.

Please choose **only one** of the following:

Country:

Denmark
Finland
France
Germany
Netherlands
United Kingdom
International/ Global
Afghanistan
Albania
Algeria
Andorra
Angola
Antigua and Barbuda
Argentina
Armenia
Australia
Austria
Azerbaijan
Bahamas,The
Bahrain
Bangladesh
Barbados
Belarus
Belgium
Belize
Benin
Bhutan
Bolivia
Bosnia and Herzegovina
Canada
Cape Verde
Central African Republic
Chad
Chile
China
Colombia
Comoros
Congo
Congo (Democratic Republic)
Costa Rica
Croatia
Cuba
Cyprus
Czechia
Djibouti
Dominica
Dominican Republic
East Timor
Ecuador
Egypt
El Salvador
Equatorial Guinea
Eritrea
Estonia
Eswatini
Ethiopia
Guinea
Guinea-Bissau
Guyana
Haiti
Honduras
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Ivory Coast
Jamaica
Japan
Honduras
Hungary
Iceland
India
Indonesia
Iran
Iraq
Ireland
Israel
Italy
Ivory Coast
Jamaica
Japan
Jordan
Kazakhstan
Lesotho
Liberia
Libya
Liechtenstein
Lithuania
Luxembourg
Madagascar
Malawi
Malaysia
Maldives
Mali
Malta
Marshall Islands
Mauritania
Mauritius
Mexico
Federated States of Micronesia
Moldova
Monaco
Mongolia
Montenegro
Morocco
Mozambique
Myanmar (Burma)
Namibia
Nauru
Nepal
New Zealand
Nicaragua
Palau
Panama
Papua New Guinea
Paraguay
Peru
Philippines
Poland
Portugal
Qatar
Romania
Russia
Rwanda
St Kitts and Nevis
St Lucia
St Vincent
Samoa
San Marino
Sao Tome and Principe
Saudi Arabia
Senegal
Serbia
Seychelles
Sierra Leone
Singapore
Slovakia
Slovenia
Solomon Islands
Somalia
South Africa
Syria
Tajikistan
Tanzania
Thailand
Togo
Tonga
Trinidad and Tobago
Tunisia
Turkey
Turkmenistan
Tuvalu
Uganda
Ukraine
United Arab Emirates
United States
Uruguay
Uzbekistan
Vanuatu
Vatican City
Venezuela
Vietnam
Yemen
Zambia
Zimbabwe
Other

Botswana Fiji Kenya Niger South Korea
Brazil Gabon Kiribati Nigeria South Sudan
Brunei Gambia,The Kosovo North Korea Spain
Bulgaria Georgia Kuwait North Sri Lanka
Burkina Faso Ghana Kyrgyzstan Macedonia Sudan
Burundi Greece Laos Norway Suriname
Cambodia Grenada Latvia Oman Sweden
Cameroon Guatemala Lebanon Pakistan Switzerland

Question 5: In which research disciplines do you work? Select all that apply. For details on the below classification, please see the Common Aggregation Hierarchy.
Check all that apply

Please choose **all** that apply:

- Medicine and dentistry
- Psychology
- Subjects allied to medicine (inc. nursing, pharmacology and health sciences)
- Veterinary sciences
- Agriculture, food and related studies
- Biological and sport sciences
- Computing
- Engineering and technology
- Geography, earth and environmental studies
- Mathematical sciences
- Physical sciences
- Architecture, building and planning
- Business and management
- Design, and creative and performing arts
- Education and teaching
- Historical, philosophical and religious studies
- Law
- Language and area studies (inc. literature)
- Media, journalism and communications
- Social sciences
- Combined and general studies
- Other:

Question 6: Select the one career stage that most accurately describes your role (as either a researcher, research support staff, or manager).
The career stages are broadly defined as:

- Junior: you are studying/training before entering your profession. E.g. MSc / PhD student, Apprentice, Intern
- Early: your work is mostly directed by someone else. E.g. Research Assistant, Postdoctoral Research Associate, Lecturer; Academic Librarian, Research Librarian, Research Software Engineer, Data Steward, Data Librarian, Technician, Research Officer, etc
  Mid: you have responsibility for your own work and have increased responsibility or influence for directing the work of others. E.g. Research Fellow, Senior Lecturer, Reader, Senior Librarian, Senior Research Software Engineer, Data Steward Group Leader, Senior Data Scientist, Research Manager, Group Leader, Head of Centre, etc

Established: you have significant experience and influence in your role, and are likely to be responsible for directing the work of multiple or large groups. E.g. Professor, Professorial Fellow, Head Librarian, Director of Library Services, Head of Department, Director of Research Computing, Service Director

Choose one of the following answers
Please choose **only one** of the following:

- Junior
- Early
- Mid
- Established

Your opinion of reproducibility

Question 7: (Mandatory) What sentence best sums up your opinion of reproducibility at the present moment? *
Choose one of the following answers

Please choose **only one** of the following:

- I began exploring implementation of reproducibility when it was still considered a novel and risky idea by my peers
- I was one of the first implementers of reproducibility practices amongst my peers, and now my peers often seek advice and information from me
- I have taken some time to adopt reproducibility practices, and look to my peers to understand which practices, tools and infrastructures I could be using
- I have a cautious approach to reproducibility, and will wait to adopt these practices until many of my peers are doing so
- I have a very cautious approach to reproducibility and I will wait until they become the norm to adopt these practices

Reproducibility Practices - Researchers and Research Support staff only

This section aims to identify any reproducibility practices that you engage with and/or support.

We will be asking about **scaling** of reproducibility. This refers to practices that help enable reproducibility to move beyond being practised by only a few individuals to become more widespread in your research context. Scalability basically entails that a practice can be adapted to a bigger scale than a few individuals in your local context.

Reproducibility practices are categorised in this survey using the taxonomy developed by Davidson et al., 2022 into the following seven categories:

1. Tools
2. Education and training in research reproducibility
3. Incentives to enhance awareness, accessibility and understanding
4. Modelling and mentoring to encourage research reproducibility
5. Review and feedback

6. Expert involvement and advice
7. Policies and procedures

More examples for each category.

Question 8: Which of the following types of practices to support scaling of reproducibility exist in your organisational environment?

Please choose the appropriate response for each item:

	Easily accessible	Accessible	Not easily accessible	Doesn't exist
Tools				
Education and training in research reproducibility				
Incentives to enhance awareness, accessibility and understanding				
Modelling and mentoring to encourage research reproducibility				
Review and feedback				
Expert involvement and advice				
Policies and procedures				

Question 9: If you selected Other, please specify:

Please write your answer here:

Question 10: Are there other types of practices to support scaling of reproducibility that you can access (please provide details)?

Please write your answer here:

Question 11: Which of the following types of practices to support scaling of reproducibility do you utilise and/or benefit from in your organisational environment?

Please choose the appropriate response for each item:

	A lot	Sometimes	Occasionally	Doesn't exist
Tools				
Education and training in research reproducibility				
Incentives to enhance awareness,				

accessibility and understanding
Modelling and mentoring to encourage research reproducibility
Review and feedback
Expert involvement and advice
Policies and procedures

Question 12: If you selected Other, please specify:

Question 13: Please rank the following types of practices to support scaling of reproducibility in the order you would like to see prioritised for support in your organisation.
All your answers must be different and you must rank in order.

Please select at most 8 answers. Please number each box in order of preference from 1 to 8.

- ☐ Tools
- ☐ Education and training in research reproducibility
- ☐ Incentives to enhance awareness, accessibility and understanding
- ☐ Modelling and mentoring to encourage research reproducibility
- ☐ Review and feedback
- ☐ Expert involvement and advice
- ☐ Policies and procedures
- ☐ Other

Reproducibility practices - all participants

Question 14: What most influences your adoption or promotion of practices to increase scaling of reproducibility?
Please choose the appropriate response for each item:

	Significant effect	Some effect	Little effect	No effect
Access to time and financial support				
Organisational support, e.g. policies, culture and/or structures				
Your line manager / supervisor's support				
Your peers' support				
Existence of incentives				
Potential to increase research impact, e.g. data and software reuse				
Availability of training and support				
Community/disciplinary				

approaches i.e. the extent to which these practices are already prevalent	
Other priorities	
Effect on innovation	
Other	

Question 15: If you selected Other, please specify:
Please write your answer here:

Question 16: Can you explain further? What dilemmas have you faced in choosing to adopt or promote practices to increase scaling of reproducibility?
Please write your answer here:

Question 17: Can you provide an example where your decision for or against implementing reproducibility practices was due to considerations such as research excellence, attracting funding or professional development needs, and the factors affecting your decision?
Please write your answer here:

Question 18: Which of the following types of practices to support scaling of reproducibility have you encouraged engagement with in your organisational environment?
Reproducibility practices are categorised in this survey using the taxonomy developed by Davidson et al., 2022 into the following seven categories:

1. Tools
2. Education and training in research reproducibility
3. Incentives to enhance awareness, accessibility and understanding
4. Modelling and mentoring to encourage research reproducibility
5. Review and feedback
6. Expert involvement and advice
7. Policies and procedures

More examples for each category.
Please choose the appropriate response for each item:

	I led the development	I highlighted to others	I advocated for the importance
Tools			
Education and training in research reproducibility			
Incentives to enhance awareness, accessibility and understanding			
Modelling and mentoring to encourage research reproducibility			
Review and feedback			

Expert involvement and advice
Policies and procedures
Other

Question 19: If you selected Other, please specify:

Please write your answer here:

Question 20: Are there any examples of enabling and/or supporting reproducibility in a scalable way that you think are particularly impressive, impactful or innovative? Please also comment on whether these were low or high effort to implement.
Please write your answer here:

Question 21: Are there any examples of enabling and/or supporting reproducibility in a scalable way that you think didn't work well? Please also comment on whether these were low or high effort to implement.
Please write your answer here:

Question 22: Do you see any risks in encouraging and/or implementing practices that support scaling of reproducibility?
Please write your answer here:

Final comments and follow up

Question 23: Do you have any other comments you'd like to make about this survey?
Please write your answer here:

Question 24: (Mandatory) Can we contact you for a follow-up conversation? We are undertaking a small number of interviews and may contact you to take part.
Choose one of the following answers

Please choose only one of the following:

- Yes
- No

Question 25: As you answered yes to the above question please supply your name and email address. Your name and email will only be used to inform you if you have allowed us to contact you again. In either case, the questionnaire will remain anonymous and your name or email will not be passed on to Knowledge Exchange or attributed to any comments or choices that you make.
Please write your answer(s) here:

- Name
- Email address

Thank you for participating in this survey. Your responses have been recorded and your unique response identifier is:
You will need to keep a note of this identifier if you wish to request the deletion of your data at a later date.

Appendix C: Interview consent form and questions

Practices that support scaling of research reproducibility in organisations

Interview consent form

Welcome to this interview on practices that support scaling of research reproducibility. This research is being conducted by Dr Michelle Barker and Professor Neil Chue Hong on behalf of the Knowledge Exchange, to expand Knowledge Exchange work on Open Science on how the practice of conducting research in a reproducible way can be scaled up from pioneers to the majority of researchers and research support staff. This research aims to understand what types of practices assist individual researchers, research support staff, and managers to scale up practices that improve research reproducibility, and builds on our recent survey.

This interview should take approximately 30-45 minutes to complete. A public report will be disseminated upon completion of this work in early 2024, to provide recommendations on the minimum conditions to support research reproducibility.

This study follows the guidance on research ethics and integrity provided by the UK Research Integrity Office, and the work is overseen by the Knowledge Exchange office. Please take time to read the following information carefully and keep it for your records.

Who is eligible to take part in this study?

This interview focuses on researchers, research support staff and managers in European research performing

- **Researchers and/or research support staff**, e.g. Research Assistant, PhD student, Postdoctoral Research Fellow, Senior Lecturer, Professors, Data Stewards, Research Software Engineer, Data Librarian, Technician, Research Officer, Data Scientist, Academic Librarian, etc.
- **Managers of academic/research areas**, e.g. Dean, Head of Department, Head of Centre, Group Leaders, etc.
- **Managers of research support/infrastructure areas**, e.g. Senior Librarian, Manager/Director/ Group Leader of areas such as Data Stewards, IT Services, Technology Transfer Office, Research Office, Library Services, Research Computing, etc.

The interviews aim to engage personnel with a variety of attitudes to reproducibility, ranging from those who already implement reproducibility practices and/or encourage others to do so, to those who have a more cautious approach to reproducibility.

Taking part in the study, risks and benefits

If you decide to take part in this study you will be answering questions regarding practices to increase scaling of reproducibility that you led, supported and/or highlighted (or that you didn't support).

Participation in this interview is entirely up to you. You can withdraw from the interview at any time, without

organisations (e.g. universities and research laboratories). You have been invited to participate in these interviews either because you gave consent to this during our recent survey, or because the researchers identified you as someone who may have relevant experience. The interview is aimed at personnel whose role potentially includes the practice and/or support of research reproducibility in any of the following categories:

giving a reason. Your rights will not be affected. You may withdraw or correct your data at any point in time until the publishing of the results of the study, by contacting us. You can withdraw your consent (to contact you for a follow-up interview or prize) at any time by contacting the lead researchers, Dr Michelle Barker and Professor Neil Chue Hong. Otherwise, this data will be kept until the completion of the study and then destroyed.

There are no significant risks associated with participation in this study.

What will happen to the results of this study?
A report will be published as research outputs. With your consent, information can also be used for future research. The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will be anonymised: any information that could, in the researchers' assessment, allow anyone to identify you, will be removed.

Data protection and confidentiality
Your data will be processed in accordance with the United Kingdom General Data Protection Regulation. All personal information collected about you will be kept strictly confidential, including any names or emails. Personal data will be deleted at the completion of this study and will only be accessible to the lead researchers. Your data will be referred to by a unique participant number rather than by name, and only anonymised data will be shared with the partners of the Knowledge Exchange network. All electronic data will be stored within the European Economic Area and United Kingdom, or only transferred outside this region as encrypted files to computers secured with passwords and disks encrypted with the default operating system functionality for the sole purpose of processing by Dr Michelle Barker, who is based in Australia.

Who can I contact?
If you have any further questions about the study or require any assistance then please contact the lead researchers, Dr Michelle Barker, michelle.barker1@my.jcu.edu.au, and Professor Neil Chue Hong, n.chuehong@software.ac.uk. If you wish to make a complaint about the study, please contact Georgia Hemings from the Knowledge Exchange, Georgia.Hemings@jisc.ac.uk.

By proceeding with the interview I agree to all of the following statements:

- I have read and understood the above information.
- I understand that my participation is voluntary, and I can withdraw at any time.
- I consent to my anonymised data being used in academic publications and presentations.
- I consent to my anonymised data being used in future research.
- I consent to my anonymised data being shared with the partners in the Knowledge Exchange network.
- I consent to the results of the study being shared and published as research outputs.
- I consent to the recording of this interview for use only by the lead researchers.

Signature:
Name:
Date:

Interview questions

Consent
- I consent to all of the above.

Reproducibility practices

1. Can you tell us about a practice (or practices) to increase scaling of reproducibility that you led, supported and/or highlighted - or that you didn't support?
2. Why did you choose to prioritise engagement with this particular practice over others?
3. What were the positive and/or negative outcomes of this on the personnel it was aimed at (not on you personally)?
4. What advice would you give others who wanted to do something similar, i.e. what factors might affect its implementation in another context, e.g. what

And thank you for participating in this interview. Your contribution is greatly appreciated.

Consent

Please sign this page and return it to the lead researchers prior to your interview.

5. Are there any evolving aspects of technology or methods (such as generative AI) that may have a particular impact on the ability to scale up this practice and/or reproducibility practices in general?
6. Do you have any other information that you'd like to share, or comments about this interview?

Appendix D: Focus group consent form

Practices that support scaling of research reproducibility in organisations

Focus group consent form

Welcome to this focus group on practices that support scaling of research reproducibility. This research is being conducted by Dr Michelle Barker and Professor Neil Chue Hong on behalf of the Knowledge Exchange, to expand Knowledge Exchange work on Open Science on how the practice of conducting research in a reproducible way can be scaled up from pioneers to the majority of researchers and research support staff. This research aims to understand what types of practices assist individual researchers, research support staff, and managers to scale up practices that improve research reproducibility, and builds on our recent survey.

This focus group should take 1.5-2 hours. A public report will be disseminated upon completion of this work in early 2024, to provide recommendations on the minimum conditions to support research reproducibility.

This study follows the guidance on research ethics and integrity provided by the UK Research Integrity Office, and the work is overseen by the Knowledge Exchange office. Please take time to read the following information carefully and keep it for your records.

Who is eligible to take part in this study?

This focus group focuses on researchers, research support staff and managers in European research performing organisations (e.g. universities and research laboratories). You have been invited to participate in this focus group because the researchers identified you as

- Stewards, Research Software Engineer, Data Librarian, Technician, Research Officer, Data Scientist, Academic Librarian, etc.
- **Managers of academic/research areas**, e.g. Dean, Head of Department, Head of Centre, Group Leaders, etc.
- **Managers of research support/infrastructure areas**, e.g. Senior Librarian, Manager/Director/ Group Leader of areas such as Data Stewards, IT Services, Technology Transfer Office, Research Office, Library Services, Research Computing, etc.

Taking part in the study, risks and benefits

If you decide to take part in this study you will be joining a small group of 3-5 peers in providing feedback on whether indicators and enablers for scaling up reproducibility practices in research-performing organisations that we have drafted constitute a valuable approach, that could assist stakeholders to explain and encourage reproducibility scaling within their own organisations.

Participation in this focus group is entirely up to you. You can withdraw from the focus group at any time, without giving a reason. Your rights will not be affected. You may withdraw or correct your data at any point in time until the publishing of the results of the study, by contacting us. You can withdraw your consent at any time by contacting the lead researchers, Dr Michelle Barker and Professor Neil Chue Hong. Otherwise, this data will be kept until the completion of the study and

someone who may have relevant experience. This focus group is aimed at personnel whose role potentially includes the practice and/or support of research reproducibility in any of the following categories:

- **Researchers and/or research support staff**, e.g. Research Assistant, PhD student, Postdoctoral Research Fellow, Senior Lecturer, Professors, Data

then destroyed.

There are no significant risks associated with participation in this study.

What will happen to the results of this study?

A report will be published as research outputs. With your consent, information can also be used for future

research. The results of this study may be summarised in published articles, reports and presentations. Quotes or key findings will be anonymised: any information that could, in the researchers' assessment, allow anyone to identify you will be removed.

Data protection and confidentiality

Your data will be processed in accordance with the United Kingdom General Data Protection Regulation. All personal information collected about you will be kept strictly confidential, including any names or emails. Personal data will be deleted at the completion of this study and will only be accessible to the lead researchers. Your data will be referred to by a unique participant number rather than by name, and only anonymised data will be shared with the partners of the Knowledge Exchange network. All electronic data will be stored within the European Economic Area and United Kingdom, or only transferred outside this region as encrypted files to computers secured with passwords and disks encrypted with the default operating system functionality for the sole purpose of processing by Dr Michelle Barker, who is based in Australia.

Who can I contact?

If you have any further questions about the study or require any assistance then please contact the lead researchers, Dr Michelle Barker, michelle.barker1@my.jcu.edu.au, and Professor Neil Chue Hong, n.chuehong@software.ac.uk. If you wish to make a complaint about the study, please contact Georgia Hemings from the Knowledge Exchange, Georgia.Hemings@jisc.ac.uk. .

And thank you for participating in this focus group! Your contribution is greatly appreciated.

Consent

Please sign this page and return it to the lead researchers prior to your focus group.

By proceeding with the focus group I agree to all of the following statements:

- I have read and understood the above information.
- I understand that my participation is voluntary, and I can withdraw at any time.
- I consent to my anonymised data being used in academic publications and presentations.
- I consent to my anonymised data being used in future research.
- I consent to my anonymised data being shared with the partners in the Knowledge Exchange network.
- I consent to the results of the study being shared and published as research outputs.
- I consent to the recording of this focus group for use only by the lead researchers.

Signature:
Name:
Date:

Knowledge Exchange
C/O Jisc
4 Portwall Lane,
Bristol, BS1 6NB
United Kingdom

T +44 203 697 5804
E ofåce@knowledge-exchange.info