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Open science for responsible innovation in Australia: understanding the expectations and priorities of scientists and researchers

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ABSTRACT

Recent arguments for responsible innovation to progress beyond the narrow focus on open access and toward open science present the opportunity for a deliberate global transition to a culture of transparent and open scientific conduct that will deliver greater societal benefit. This paper presents results from a survey of 171 Australian scientists, researchers and other professionals on their expectations and perspectives of transparency and openness in current scientific research practice. The results suggest that for this cultural transition to occur, the responsibility for strengthening transparency and openness must be undertaken not only by scientists and researchers, but also research funding and delivery agencies, and even those beyond the research and innovation sector. These findings are a first step towards defining and understanding what open science means in an Australian context, and what shifts are needed from researchers, research institutions and policy makers to move toward open science for responsible innovation.

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Open access; openness; open science; responsible innovation; transparency

Introduction

Globally, there has been a steady move toward open science over recent years. However, institutional commitments to open science have tended to begin with a focus on the more narrowly defined open access to research data, findings and outputs. This has been evidenced by the commitments to open access in the European Commission's Horizon 2020 program (European Commission 2011); a commitment later reaffirmed and expanded by the Commission with the call for 'open innovation, open science and open to the world' (European Commission 2016). Along similar lines, international coalitions between scientists (e.g. OA 2020, established in 2015) and research funders (cOAlition S n.d., established in 2018) have formed to promote open access, whilst a number of countries including France, Denmark and Sweden have begun to develop national open access implementation plans (MESRI 2018; MHES 2018; Swedish Research Council 2015).

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In Australia, there has also been a shift toward establishing a national strategy for open access driven by the Productivity Commission (Productivity Commission 2016), advocacy groups including the Australian Open Access Strategy Group (AOASG), the Council of Australian University Librarians (CAUL), and the Australian Library and Information Association (ALIA); all supported by the recent Excellence in Research Australia report (Australian Research Council 2019). In lieu of a national framework for open access, the Australian Government's major research funders, the Australian Research Council (ARC) and the National Health and Medical Research Council (NHMRC), have open access policies in place (Australian Research Council 2017; National Health and Medical Research Council 2018), as do half of Australia's universities (AOASG and CAUL 2019) and many of Australia's publicly funded research agencies (PFRAs).

Justifications for open access in Australia are many and varied. For some, including the Productivity Commission, open access is expected to improve cost efficiencies in the publication process, as well as enable 'faster and wider dissemination of the knowledge and ideas contained within them' (Productivity Commission 2016, 29). This unlocks the potential for increased benefits associated with open access policies, and seeks to improve research integrity, foster collaboration, and enhance track record and assessment processes that contribute to 'a stronger knowledge economy' (National Health and Medical Research Council 2018, 1). Open access is also anticipated to build public trust and engagement in science, as well as promote greater translation of science into policy (AOASG & CAUL 2019).

Noting the breadth of benefits sought from open access initiatives in Australia, this paper offers a timely and valuable contribution in extending this current focus towards open science. In this paper we seek to return to the underlying principles of transparency and openness so that we might work towards establishing a shared understanding of what open science means for Australian scientists, researchers and other professionals, and how we might go about achieving it. Consistent with efforts globally (European Commission 2019), our language shifts deliberately from the narrow focus on *open access* and the publication of science and toward the goal of *open science*; a more transparent and open scientific practice that is assumed to ultimately deliver greater benefit for society.

Knowledge creation and dissemination have a complex history within scientific culture (Hessels and van Lente 2008) and have to a large extent been developed around publication methods (Bartling and Friesike 2014). While this explains the focus on open access, open science calls for a cultural change that challenges traditional institutional modes of knowledge creation and dissemination. In some fields, this has been expressed as an increased focus on the commercialisation of scientific research (Caulfield, Harmon, and Joly 2012). For some, this introduces a tension with the open science model that promotes collaboration and open sharing while for others, it signals an opportunity to move more rapidly from research to open innovation and societal impact (Friesike et al. 2015; Tait 2017). However, at the heart of the open science model lies an assumption that scientific research will be guided and developed by its societal relevance (Rosenlund, Notini, and Bravo 2017). Despite this, it is not always clear how that will be achieved or by what measures. We define open science in this research as 'transparent and accessible knowledge that is shared and developed through collaborative networks' (Vicente-Saez and Martinez-Fuentes 2018, 428). This implies moving beyond the traditional modes of knowledge creation and dissemination and a willigness to challenge

the way these activities have occurred in universities and research institutions, and that have often been structured around scientific disciplines (Hessels and van Lente 2008). In doing this, we also seek to identify to what extent Australian scientists and researchers identify and challenge their own scientific practice and institutions in advancing the broader goals of open science and if they do, how they anticpate this being realised.

The paper is structured as follows. First, we outline the rationale for conducting this research on open science within the context of responsible innovation in Australia. We then outline the research methods and approaches used to analyse the data collected in this research. Key findings and priorities on transparency and openness in Australian science are presented. We first present the quantitative results that describe expectations and beliefs about current practice, and then analyse the findings of the qualitative data to identify priorities for improving transparency and openness. Finally, we note the limitations of this study, opportunities for further research and conclude with a brief discussion on the implications of this research.

Open science for responsible innovation

The aim of this research is to elicit the perspectives and priorities of scientists, researchers and other professionals working in the Australian research and innovation system on open science in particular, and the implications of this for responsible innovation in Australia, more generally. The concept of responsible innovation has both academic and normative origins inspired by a desire to ensure 'science and innovation are directed at, and undertaken towards, socially desirable and socially acceptable ends, with connotations of trust and integrity' (Owen et al. 2013, 27). While responsibility has always been part of the central narrative of research practice, responsible innovation has emerged over the last decade as a broader framework based on the normative dimensions of building anticipation, reflexivity, inclusion and responsiveness into scientific research practice and the outcomes generated from it (Stilgoe, Owen, and Macnaghten 2013). In many ways, this reframing of responsibility has been a call to lift scientific research practice beyond established codes of conduct and ethical review to realise greater and more tangible societal benefit (Finkel 2019). Importantly, the goal is not to replace those codes and formal requirements, which remain essential to achieving research integrity, but rather to find ways to enhance the value, benefit and impact that can be generated from science for society.

The broad context for this research is framed by the emergent use of the term 'responsible innovation' in Australia, and by the greater need to understand what this really means for both practice and our expectations of research and development in this context (Ashworth et al. 2019). While responsible innovation has been used extensively in Europe over the last decade (Owen, Macnaghten, and Stilgoe 2012; Stilgoe, Owen, and Macnaghten 2013; von Schomberg 2013) and to some extent in the United States (Guston et al. 2014), its adoption in Australia is relatively recent. For example, in 2017, Australia's national science agency and largest PFRA, the Commonwealth Scientific & Industrial Research Organisation (CSIRO) established a new research program in responsible innovation to examine 'the interface of science and technology with society [and] to ensure that emerging science domains can proceed responsibly and deliver positive impacts for society' (CSIRO 2019). In 2018, the Australian Council of Learned Academies (ACOLA) published an outlook report on synthetic biology in Australia that emphasised

the importance of adopting responsible innovation in the development of synthetic biology research and industries (Gray et al. 2018). Later that year, the Australian Academy of Science (AAS) called for a framework for responsible research and innovation as a commitment to the idea that the 'Australian community has a right to expect that it will benefit from its investment in science' (AAS 2018, 2). In 2019, the Australian Human Rights Commission called for a responsible innovation organisation to guide and govern the use of artificial intelligence (AI) in Australia (Australian Human Rights Commission & World Economic Forum 2019). This adoption of the concept of responsible innovation by several significant institutions over a relatively short timeframe in Australia highlights growing commitment to generating broader societal benefit from scientific research and innovation. However, there remains a need to examine what this really means in practice.

Open access and open science are terms that are widely used, often interchangeably. They are emerging fields of research and practice in their own right and there are a multitude of definitions and frameworks in use (Vicente-Saez and Martinez-Fuentes 2018). Often however, open science is considered to be comprised of the four components of: *open access*, which refers to making research outputs and publications available; *open data*, which refers to the publication, sharing and re-use of data collected in research; *open source*, which refers to software that can be freely accessed; and *open reproducible research*, which is the practice of open science that will allow for research to be independently reproduced (and includes sharing research practices throughout the course of the work flow, not only the outputs of that research, such as key decisions, data management protocols, software selection, etc.) (Andreoli-Verbasch and Mueller-Langer 2014; Pontika et al. 2015; Sullivan, DeHaven, and Mellor 2019).

However we define these terms, according to the European Commission's H2020 program, open access and open science are a core pillar of responsible innovation (European Commission 2011; Christensen et al. 2020) that will improve the circulation of knowledge in society, foster innovation and strengthen the knowledge economy. This commitment is further extended in the scholarly literature. Rather than open access and open science, Owen et al. (2013) and Stilgoe, Owen, and Macnaghten (2013) work with the dimension of openness in responsible innovation, which they view as open and free access to and communication of the results of research. However, they also extend this to sharing the purposes, risks, uncertainties, implications and potential uses of the research. Sharing this greater range of information about research is thus seen to facilitate more inclusive deliberation in relation to research and its purpose in the world. It is anticipated this will create benefits such as more informed debates, stronger foundations for decision-making, transparency, and more equitable access to knowledge (in turn reducing power asymmetries in a knowledge economy) (Hessels and van Lente, 2008).

Accompanying this, there is also a view that the more familiar people are with science and scientific processes, the more likely they are to trust and support investment in it (Bauer, Allum, and Miller 2007; Stilgoe, Lock, and Wilsdon 2014). Communicating science is one avenue that may contribute to building and maintaining public support (Palmer and Schibeci 2014). Conversely, a lack of engagement between science and society may erode trust in research and public institutions. This assumes an effective relationship between science and society will be built on principles of transparency and openness: '[t]ransparent in the values and assumptions that underpin chosen science pursuits, and open to new ideas, divergent perspectives as well as making scientific research

accessible to all levels of a scientifically engaged society' (Herington, Coates, and Lacey 2019, 13).

This range of benefits associated with open science is not unlike the breadth of benefits outlined at the outset of this paper and that are present in the range of open access policies that exist in Australia. For these reasons, we set about examining the views of those working in, managing and funding scientific research in Australia to better understand how they view current practice and future priorities in relation to the role of transparency and openness, and what this might mean for the practice of open science.

Research methods

This research is drawn from a broader study on the science-society relationship and responsible innovation in Australia (see Herington, Coates, and Lacey 2019). The broader study, conducted in April 2019, used an online survey instrument to examine what scientists, researchers and other professionals working in the Australian research and innovation system understand as responsible innovation. The survey was designed to capture both quantitative and qualitative responses of participants. In doing so, we set out to gain an understanding of their expectations of responsible innovation against the following three themes:

- Transparency and openness in research and innovation;
- The role of inclusive, and meaningful dialogue between science and society; and
- Ensuring ethical and responsible conduct of science.

In this paper, we focus only on the findings relating to the theme of transparency and openness in research and innovation.[1] We do this in order to provide a deeper analysis of how scientists, researchers and other professionals understand their own responsibilities in relation to transparency and openness, and what this reveals about how we view open access and open science in the Australian context. Because the concept of open science often carries subjective meanings and is prone to misinterpretation (Fecher and Friesike 2014), we deliberately focused on the principles of transparency and openness in designing this research. The section of the survey on transparency and openness was introduced with the following statement to orient participants:

> A robust, open relationship between science and society requires a foundation built on principles of transparency and openness. This relationship requires transparency about the values and assumptions that underpin research and innovation, and openness to new ideas and divergent perspectives.

The use of definitions and other materials is an accepted approach in survey design that helps to provide a common base for understanding the concepts under consideration and for answering questions about them (Volken, Wong-Parodi, and Trutnevyte 2017; Lacey et al. 2019). Similar definitions were provided for all themes in the survey. Using these guiding principles of transparency and openness, we explore expectations, current practice and key priorities from the perspective of scientists, researchers and other professionals working in the Australian research and innovation system.

Research design and survey

Participants for the survey were recruited via a non-probability, voluntary sampling method through professional networks, institutional internal communication and key informants. This sampling strategy was employed to capture the perspectives of scientists, researchers and other professionals using accessible professional networks, and to facilitate the participation of those interested in doing so. This research did not aim to produce generalisable results with a sole focus on the quantitative data, rather the aims of the research were to capture rich and contextual data from a sample of this group of professionals. The mixed-methods survey questionnaire was deliberatively designed to include complementary quantitative and qualitative items to generate an in-depth dataset. Given the sampling strategy, results from the survey are not generalisable and should not be interpreted as such. Potential participants were provided a link to the survey for online completion. The survey was open for a total of 15 days in April 2019. During this time, 174 responses were recorded, of these, 3 were removed due to invalid responses. Of the 171 valid responses, 123 were complete, having provided answers for all survey items. All valid responses were included in the analyses.

In addition to demographic questions, the survey instrument included a series of Likert scales and open text boxes to capture responses in relation to transparency and openness.[2] The transparency and openness theme included one Likert scale, comprising three survey-items measuring participants' *expectations* of the transparency and openness of scientists, research delivery agencies and research funding agencies; and one Likert scale, comprising nine survey-items that captured what they *believe about the current practice* of science funders, scientists and the institutional arrangements of Australian science funding and research delivery agencies with respect to transparency and openness (i.e. a total of 12 variables were tested). The items included in the Likert scales asked survey participants to indicate their level of agreement with a series of statements on a 7-point scale (1 = strongly disagree, 4 = neither agree/disagree, 7 = strongly agree).

Using the data captured from the survey, we explore the expectations and beliefs of research and innovation stakeholders in Australia to assess the current state of open science. The potential for improving transparency and openness of science practice and expectations are discussed, alongside insights gained from the qualitative data analysis of participants' priorities. Before presenting the results and discussion, we present the analytic approach and participant characteristics.

Analytic approach

The analytic approach used in this paper is suited to the non-probability voluntary sampling strategy employed in generating a participant sample for the survey, and to the categorical nature of the variables of interest from the transparency and openness theme. The survey data analysis presents findings on the perceptions of Australian scientists, researchers and other professionals. It does not attempt to generalise or argue a case for how all Australian scientists and researchers view this sector, nor does it attempt to present reasons for assumptions of causality.

For the purpose of this paper, variables from the transparency and openness theme were analysed with the use of descriptive summary statistics. Tests of association were

also conducted to explore whether there may be significant associations between the age, gender and career stage of participants. Relevant literature suggests that participant age would not be significantly associated with perceptions and expectations of open science, but that gender and career stage may (Haeussler et al. 2014). Career stage, as operationalised in the analysis as length of time working in the Australian research and innovation system, may influence participants' perceptions and expectations. Career stage could also be considered as an indicator of participant position or seniority, which may also influence their perspectives of the Australian research and innovation system. We use chi-square statistic to test for associations between the Likert-scale variables capturing transparency and openness perspectives and the demographic characteristics of participants. The distribution of responses on both demographic and Likert-scale variables presented challenges as participant responses were often skewed. Coupled with the small sample size, these distribution characteristics meant that many of the contingency tables of the open-science and demographic variables did not meet the Pearson's chi-square assumptions and therefore had potential for a Type II error. The tests of association are reported later in the paper with these caveats taken into account. For the quantitative data analysis, we used the general-purpose statistical software package Stata (StataCorp 2017).

In order to contextualise the quantitative findings, we also present a qualitative analysis of participants' priorities on transparency and openness. The survey instrument included an open-ended text question seeking participants' top three priorities or issues related to transparency and openness in the Australian research and innovation sector. Each participant was asked to write only one or two sentences per priority and further ranking of their top three priorities was not required. Collectively, participants submitted 303 priority or issue statements on transparency and openness. An Automated Content Analysis (ACA) was conducted on this data using the computer-aided software package Leximancer (Smith and Humphreys 2006).

ACA is a text-mining method that uses text-parsing and machine learning to discover and learn, based on data and a suite of algorithms, key concepts, topics and themes (Blei 2012). ACA generally follows a three-stage approach (Nunez-Mir et al. 2016). First, concept seeds are identified using either unsupervised concept seeding (automated) or supervised via selection. Second, concepts are developed and defined using text-grounded, word disambiguation and/or user-defined thesaurus construction. Third, original text is re-classified based on the learned concepts and indexed accordingly. The final outputs from an ACA procedure may include concept maps, trend analyses and reports detailing concept occurrence and co-occurrences.

Following ACA procedures, Leximancer can reliably and reproducibly identify main concepts and themes embedded within text, based on the frequency and patterns of co-occurrence. Leximancer was employed to interrogate the priority statements for emerging subthemes in the text. In this way, Leximancer serves to reduce the risk of subjectivity and bias (Sotiriadou, Brouwers, and Le 2014) during the initial stages of an inductive, exploratory qualitative data interrogation such as this research. Specifically, we used Leximancer to analyse all priority statements from respondents submitted through the survey, to automate the process of determining key themes and concepts found in these statements. The data was then further qualitatively codified, that is each priority statement was coded into one of the four emergent thematic areas, to interpret and articulate these identified themes. Before presenting the quantitative and qualitative results, we outline the participant characteristics.

Participant characteristics

Table 1 presents the demographic characteristics of the survey participants. Nearly half of participants were male (46.2 per cent), 52.6 per cent were female and 1.2 per cent responded as other. Most participants were aged between 40–49 years (31.5 per cent) or 30–39 years (26.4 per cent). As might be expected, nearly all participants held a postgraduate qualification (89.5 per cent). Academic career stage was measured by calculating the number of years since completion of postgraduate qualification, as a substitute measure of PhD conferral. Just under half of the participants (47.4 per cent) were established in their career having completed postgraduate studies prior to 2003. Most participant workplaces were in either

Table 1. Survey participant characteristics (*n*, column per cent).

	No.	%		No.	%
Gender			**State/Territory of workplace**		
Male	79	46.2	New South Wales	53	31.2
Female	90	52.6	Queensland	50	29.4
Other	2	1.2	Victoria	34	20
Total	171	100	Western Australia	22	12.9
Age			South Australia	4	2.4
20–24 years	2	1.2	Tasmania	2	1.2
25–29 years	10	5.8	Northern Territory	2	1.2
30–34 years	23	13.5	Australian Capital Territory	1	0.6
35–39 years	22	12.9	Overseas	2	1.2
40–44 years	24	14	Total	170	100
45–49 years	30	17.5	**Remoteness area**		
50–54 years	19	11.1	Major City	155	92.3
55–59 years	16	9.4	Inner Regional	7	4.2
60–64 years	15	8.8	Outer Regional	6	3.6
65–69 years	4	2.3	Total	168	100
70–74 years	4	2.3	**Employer Industry (ANZSIC)**		
75–79 years	1	0.6	Tertiary Education	121	73.8
80–84 years	1	0.6	Scientific Research Services	28	17.1
Total	171	100	Civic, Professional & Other Interest Group Services	4	2.4
Indigenous status			Management and Related Consulting Services	2	1.2
Indigenous	1	0.6	Central Government Administration	2	1.2
Non-Indigenous	166	99.4	Land Development and Site Preparation Services	1	0.6
Total	167	100	Computer System Design and Related Services	1	0.6
Highest level of education			State Government Administration	1	0.6
Postgraduate level degree	154	89.5	Justice	1	0.6
Graduate diploma and graduate certificate	6	3.5	School Education	1	0.6
Bachelor degree level	11	6.4	Hospitals	1	0.6
Certificate level	1	0.6	Museum Operation	1	0.6
Total	172	100	Total	164	100
Career stage			**Occupational category**		
Early	37	24	Researcher/scientist	72	42.6
Mid	44	28.6	Teaching and research academic	44	26
Established	73	47.4	PhD student	16	9.5
Total	154	100	Science/research manager	14	8.3
Year completed highest level of education			Policy manager	8	4.7
2019–2014	45	26.2	Consultant	4	2.4
2013–2004	50	29.1	Educator	3	1.8
2003 and earlier	77	44.8	Other	8	4.7
Total	172	100	Total	169	100

New South Wales or Queensland at 31.2 per cent and 29.4 per cent, respectively, and nearly all were located in a major Australian city (92.3 per cent).

Our sampling and recruitment strategy targeted publicly funded research agencies (i.e. PFRAs) and higher-education institutions (i.e. universities), which comprise two of the major research implementation functions in Australia (Lacey, Ashworth, and Witt 2019). This is illustrated in the participants' place of work and occupation type. Participants were asked the name of their employer. These responses were coded according to the Australian and New Zealand Standard Industrial Classification (Australian Bureau of Statistics 2016). Most survey participants worked for an employer in the tertiary education industry (73.8 per cent), or at a scientific research institution (17.1 per cent). Occupational categories were thematically coded, using the open-text responses provided by participants on questions about their primary occupation and primary responsibility in their role. The occupational categories aimed to capture both the main occupation of the participants and their position in the Australian research and innovation sector. For example, participants coded to the 'science/research manager' category had a role in overseeing or managing science or research work and typically included occupation titles such as, 'Faculty Dean' or 'Senior Research Manager'. Most survey participants were employed as either researchers/scientists (42.6 per cent) or as teaching and research academics (26 per cent).

Differences in some of the demographics, such as career stage, employer industry or occupation of survey participants may potentially influence participants' relationship to stakeholders in the Australian research environment and therefore may also affect their perspectives on the nature of the science-society relationship. In capturing this data, we aimed to quantify the variety of roles and positions of the participants in the research and innovation sector in Australia, and to allow for further analysis of any potential variations in the perspectives and opinions expressed by participants. In the next section of the paper, we present summary statistics of the opinions and perspectives of participants on questions about transparency and openness, followed by results on associations between participant career stage, occupation and employer industry.

Results and discussion

In this section, we first present the findings from the descriptive analysis of the quantitative survey items of interest. The descriptive statistics suggest a discrepancy between what the survey participants expect from scientists, research delivery agencies and research funding agencies in terms of transparency and openness, and what they perceive to be happening in the current practice of these stakeholders. We then present the findings from the ACA of the open-text responses from participants on transparency and openness. These extend the descriptive statistics findings with several themes about what participants identify as their priorities for strengthening open science in Australia. These suggestions may help mediate the discrepancy between expectations and current practice.

Open science expectations and perceptions of current practice

Participants were asked to rate their level of agreement with a series of statements about their expectations of scientists, research delivery agencies and research funding agencies following principles of transparency and openness in their practice. Figure 1 illustrates

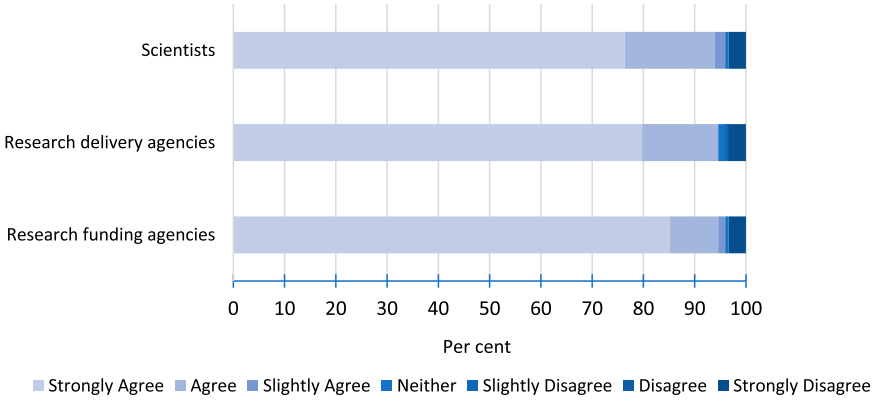

Figure 1. Expectations of Australian stakeholders to follow principles of transparency and openness (per cent).

Note: Participants were asked: 'Please rate the extent to which you agree or disagree with the following statements'. The statements were the same for each stakeholder, as follows: 'I expect [Australian stakeholders] to follow principles of transparency and openness'.

that the survey participants hold high expectations of key stakeholders in the Australian research and innovation system to follow such principles. The majority of participants strongly agreed that scientists (76.35 per cent), science delivery agencies (79.73 per cent) and science funding agencies (85.14 per cent) should follow principles of transparency and openness. When responses for agree and strongly agree categories are combined, we can see that the majority of participants, at about 94 per cent for each statement, are in high support for principles of transparency and openness.

Participants were also asked about their level of agreement with statements about the current practice of science funding stakeholders in Australia. As presented in Figure 2, the statements explored the communication of decisions from various avenues for science funding in Australia, namely government, philanthropic and private/industry funders. Overall, the data from these three items indicated that survey participants have low levels of confidence that Australian science funders are effectively communicating their decisions to the public. Over 50 per cent of participants slightly to strongly

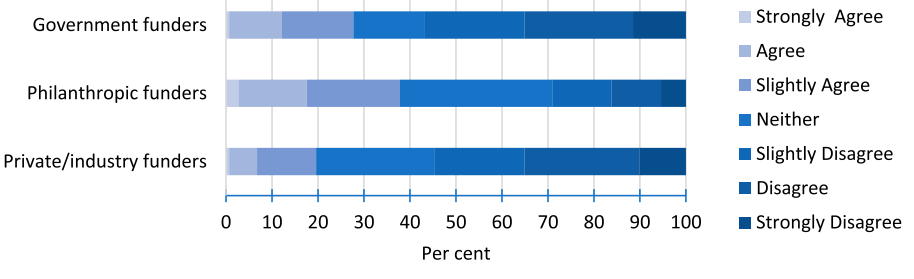

Figure 2. Beliefs about Australian science funders effective communication of decisions to the Australian public (per cent).

Note: Participants were asked: 'Please rate the extent to which you agree or disagree with the following statements'. The statements were the same for each stakeholder, as follows: 'I believe [government funders, philanthropic funders, private/industry funders] of Australian science effectively communicate their decisions to the Australian public'.

disagreed that government and private/industry funders (56.76 and 54.73 per cent, respectively) effectively communicated their decisions to the Australian public. The responses to these items also suggest an uncertainty about the communication of decisions by philanthropic funders, with over a quarter (33 per cent) of participants stating they neither agreed nor disagreed. A quarter of participants were also ambivalent about private and industry funders' communication. However, more participants agreed (37.8 per cent) that philanthropic funders communicated their decisions, than disagreed (29 per cent) when responses from slightly-strongly agreed, and slightly-strongly disagreed, were combined. This was not the case for government and private/industry funders, with more participants disagreeing than agreeing with these statements. Overall, the responses to the statements on key stakeholders' communication of their decisions suggested participants have generally negative, or ambivalent beliefs, which may be illustrative of an underlying perception of a lack of transparency and openness from these funding bodies.

Figure 3 presents participant perspectives of the communication and conduct of Australian scientists with respect to transparency and openness. Whilst most participants believe the conduct of Australian scientists is transparent and that they effectively communicate with the public, many also thought that Australian scientists could do better. When slightly-strongly agree responses are combined, 53.39 per cent of participants agree that Australian scientists effectively communicate their research to the Australian public, and 64.87 per cent agree that Australian scientists' conduct is transparent. However, the majority of responses in the agree categories are in the slightly agree or agree range, suggesting that participants were not overall in strong agreement with these statements. Further, in comparison to the responses to research funding stakeholders, the survey data shows that participants perceive scientists to be better placed to communicate to the public than research funding bodies.

Questions were also included in the survey to gauge perceptions on how current institutional arrangements encourage transparency and openness from Australian scientists, as shown in Figure 4. Institutional arrangements are broadly taken to encompass the collection of policies, systems and processes within research delivery and research funding organisations that enable them to plan, manage and deliver their activities effectively. These questions provide further context to the responses to previous questions in that

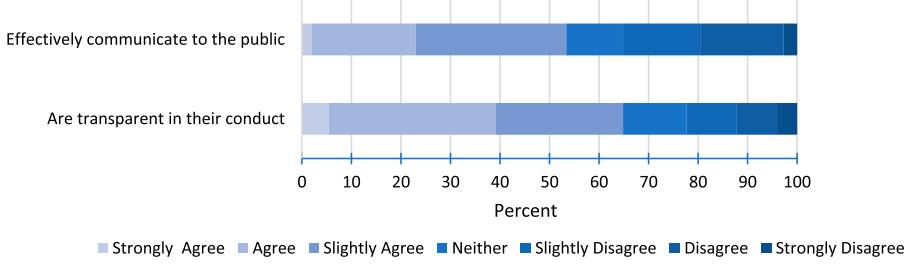

Figure 3. Beliefs about communication and conduct of Australian Scientists.

Note: Participants were asked: 'Please rate the extent to which you agree or disagree with the following statements'. The statements were: 'I believe Australian scientists effectively communicate their research to the Australian public', and 'I believe the conduct of Australian scientists is largely transparent'.

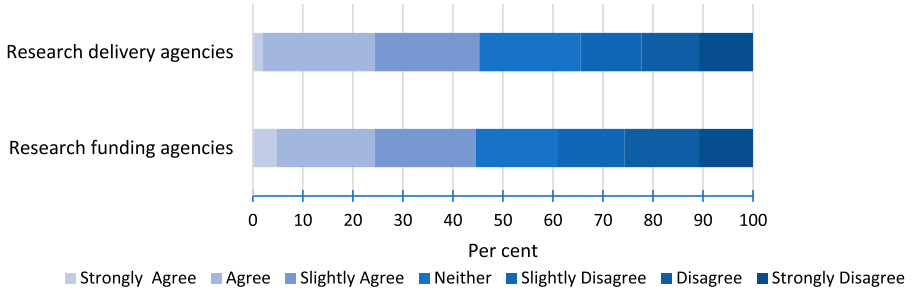

Figure 4. Research funding/delivery agency institutional arrangements encourage transparency and openness.

Note: Participants were asked: 'Please rate the extent to which you agree or disagree with the following statements'. The statements were the same for each stakeholder, as follows: 'I believe the current institutional arrangements in [research delivery agencies/research funding agencies] encourage openness and transparency from our scientists'.

it not only highlights a potential gap between expectations and current practice for open science in the Australian research and innovation system, but it also begins to highlight why such a gap may exist. Less than half of participants agreed that institutional arrangements encourage transparency and openness (45.28 per cent for research delivery agencies and 44.59 per cent for research funding agencies), with a substantial proportion of responses in the 'neither' category at 20.27 and 16.22 per cent, respectively. These responses, while mostly suggesting that research agencies support transparency and openness, indicate that greater transparency and openness is perceived to be constrained by institutional arrangements within research funding and delivery agencies. In other words, many participants believed that better facilitation and support through institutional arrangements in science delivery and funding for these core principles of scientific best practice are required.

Finally, overall perceptions of transparency and openness were measured with respect to science funding and the accessibility of science to the public (Figure 5). Responses to these general statements about transparency and openness suggest that, overall, participants believed science funding decisions are not particularly transparent, nor is science

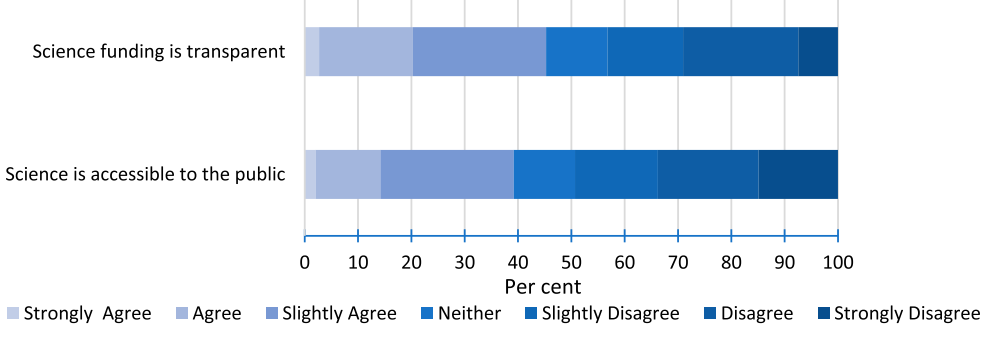

Figure 5. Overall perceptions of transparency and openness in Australian science.

Note: Participants were asked: 'Please rate the extent to which you agree or disagree with the following statements'. The statements were: 'On the whole, I feel scientific research is accessible to all levels of a scientifically engaged public', and 'I believe the current decisions about the funding of science are largely transparent'.

generally accessible to the public. Most survey participants perceived scientific research to not be accessible to all levels of a scientifically engaged public, though slightly more participants believed that current decisions regarding the funding of science are transparent. For instance, when the slightly-strongly disagree, and slightly-strongly agree statements are combined, slightly more participants agree that science funding decisions are transparent (45.27 per cent) than disagree (43.24 per cent). While for the statement on science being accessible, more participants disagreed (49.32 per cent) than agreed (39.19 per cent). For both statements, one-quarter of participants selected the 'neither agree/disagree' response. This suggests either complacency on these statements, or a lack in confidence to respond either favourably or unfavourably with respect to general perceptions of the transparency of funding and accessibility of science to the Australian public.

Are demographic factors associated with perceptions of open science?

Demographic characteristics of participants were also tested for significant association with the transparency and openness survey variables. Age, gender, occupation and career stage were included in this analysis. However, the distribution of the sample meant that many of the contingency tables did not meet the assumptions of the Pearsons chi-square test and therefore produced invalid results. To increase the suitability of the data for the contingency tables, response categories for occupational category were combined to produce more robust results. Strongly, slightly and disagree categories, and strongly, slightly and agree categories were also combined due to response distribution sparseness.

Age and gender did not produce any statistically significant associations with any of the transparency and openness variables. The lack of statistical significance of age of respondents is consistent with a study by Haeussler et al. (2014) on sharing in science practice, though not for gender. Haeussler et al. (2014) found males to be less likely to share in their science practice than females. The results on age and gender should be interpreted with caution, however, due to the aforementioned chi-square test assumption violation.

Some statistically significant and valid associations were found with career stage and occupation. Occupational category of participants was tested for association with each of the 12 variables measuring perceptions and opinions of transparency and openness. Of these 12 variables, we found significant association with participants' level of agreement that government funders effectively communicate decisions ($p < 0.05$). Overall, most participants disagreed with the statement that government funders effectively communicate funding decisions, with 53.9 per cent of researchers and scientists disagreeing with the statement, 55 per cent of academics, 63.2 per cent of managers, and 90 per cent of 'other' occupations, which included consultant, educators and independent professionals, disagreeing. A statistically significant association between participant level of agreement that science funding overall is transparent ($p < 0.05$) and occupation was also found. More academics and managers (both 47 per cent) disagreed with this statement than researchers/scientists (37 per cent).

Career stage was also tested for association with each of the 12 variables measuring perceptions and opinions of transparency and openness. Of the 12 variables, we found significant association with participants level of agreement that government and philanthropic funders communicate decisions effectively (both $p < 0.05$). Slightly more early to mid-

career participants (60 per cent for both) disagreed that government funders effectively communicate decisions, than established career participants (53 per cent). While beliefs on philanthropic funding decisions communication was associated with career stage, responses between career stage were fairly uniform across disagree, neither and agree response categories.

Career stage was also statistically significantly associated with levels of agreement on the belief that institutional arrangements of research delivery agencies ($p < 0.05$) and research funding agencies ($p < 0.01$) encourage transparency and openness. Early career participants disagreed more than mid or established career participants that the institutional arrangements of research delivery and funding agencies (40 per cent and 51.4 per cent, respectively) were transparent. The responses of early career participants also suggest greater ambiguity about institutional arrangements for research delivery and funding agencies though; for both items early career researchers were proportionality more unsure.

Priorities for strengthening open science in Australia

Survey participants were also asked to qualitatively describe their top three priorities or issues to ensure transparency and openness in an open-text response question. A total of 303 priority statements were submitted and clustered around issues related to: science outreach ($n = 111$), science funding ($n = 100$), openness and open access ($n = 68$) and media engagement ($n = 24$). We examine each theme in turn.

Science outreach and the transition from deficit to dialogue

The theme of science outreach broadly relates to how science is used to engage and communicate with various stakeholders, including society generally. It includes commentary and priorities on: (1) with whom science is, or ought to be, engaging, (2) what information to provide and/or collect, and (3) how to go about this engagement. It is the most dominant theme to emerge from the data with 111 priority or issue statements coded against it.

In analysing the priority statements for this theme, participants generally perceived that open science is not simply a matter of improving the one-way communication between science and society but requires opening a two-way dialogical form of public engagement. Such a shift from 'deficit to dialogue' (Stilgoe, Lock, and Wilsdon 2014, 5) is consistent with the transition found in the literature on public understanding of science and reflects a move away from what has been described as the traditional deficit model. In the deficit model, the issue of poor public engagement is framed as a lack of knowledge among the public and the solution is, therefore, always framed as a need to provide more information (Hansen et al. 2003; Sturgis and Allum 2004). In the words of participants, the priority for this transition was described as follows:

> There are too few avenues for 'society' to engage in development of research agendas – 'society' is typically only thought of as the consumers at the end of a long scientific process.

> Transforming concepts of 'transparency and openness' from their current focus on the communication of research outcomes to a more transparent discussion of, and dialogue around, the values underpinning research.

But do scientists have the means and the capability to move from deficit to dialogical science outreach? And what should they be doing to create or support these dialogues

with diverse publics? The data alluded not only to transitions in the nature and scope of science outreach activities, but also the skills and competencies required to enable this transition. A further challenge arises in thinking about the scale of such efforts. As Stilgoe, Lock, and Wilsdon (2014) point out the scale of public engagement when it does happen often resembles the 'mini-publics' described by Goodin and Dryzek (2006); small enough to be deliberative and representative in democratic terms but not statistically representative of the wider public. While these small and targeted engagements make an important contribution and may be important for specific or even political ends, they in no way reflect the global scale of the scientific endeavour and the potential of open science as it is often framed. While most participants believed that science was not accessible to all levels of scientifically engaged public and recognised the role of science outreach, a deeper analysis of why public engagement, and to what end, is needed to navigate a more considered approach to the institutional arrangements that might enable this approach.

Transparency of science funding

A total 101 priority statements clustered within this theme relate to the transparent and open nature of science funding. Although most statements referred to publicly funded research mechanisms, several priorities highlighted the need for increased transparency of industry-funded research (and to a lesser extent, philanthropic funding). In the discussion of transparency of funding, one participant expressed this as follows:

> Public transparency and public accountability for research funded by all sources, but particularly government (taxpayer accountability) and industry (to ensure scientists are not pressured by industry objectives to moderate findings).

While there were some concerns noted about potential political or industry interference in funding decisions (or the research generated as a result), there was a much greater focus on the need to ensure public or taxpayer accountability for funding decisions. The mechanisms suggested for achieving this ranged from including the public in funding decisions (e.g. via public representation on review committees), applying tests for taxpayer accountability using criteria such as equity and inclusivity, clearly demonstrating that societal input was incorporated in funding decisions, through to simply making the funding decisions publicly available. While major research funders in Australia already apply criteria that requires evidence of how the research is in the national interest (ARC 2015), the data indicated that these suggestions for increasing accountability of funding was seen as a pathway for building public confidence in science. However, the drivers of trust in science are complex; how and to what extent transparency of funding decisions contributes to public trust needs to be tested (Peerenboom 2002; Funk 2017).

This desire for increased transparency of funding was not only directed at the public. Many of the priority statements also highlighted an overarching desire for greater clarity about funding processes and decisions from the participants themselves. These findings are consistent with the descriptive statistical analysis on overall perceptions of transparency and openness in Australian science, where 55 per cent of participants either disagreed or were ambiguous (responding 'neither') to a statement on the transparency of science funding. There was some evidence in the ACA results that career stage may play a role in how transparency of funding was perceived with some priority statements calling for

track record to be removed as a criterion for research awards, that increasing transparency would end the perceived practice of 'captain's picks', and a general desire to see more evidence of the outcomes of national funding decisions. The role of competition also emerged in this theme expressed by one participant as follows:

> Scientists are forced to be competitive with each other rather than collaborative, especially within a diminishing market.

Here the call was for better institutional arrangements and support from research funding agencies to better facilitate collaboration, including multidisciplinary collaboration. This finding was also consistent to the tests for statistically significant associations between levels of agreement on the belief that institutional arrangements of research delivery agencies ($p < 0.05$) and research funding agencies ($p < 0.01$) encourage transparency and openness. As reported earlier in the paper, early career participants disagreed more with these statements than mid or established career participants. Haeussler et al. (2014) have examined patterns of information sharing among academics and have found that this tends to be context dependent depending on the trade-offs between the potential for greater reciprocity and a loss in competitiveness. In their research, career stage played a role in reducing information sharing behaviours in individuals but only where the researcher held an untenured position. This matters as if we are truly contemplating the broader societal value generated by open science, because it means this outward impact from scientific research needs to be aligned with professional recognition and incentives for individuals. While research institutions in Australia are increasingly moving toward impact reporting, professional recognition and career advancement for scientists and researchers continue to be aligned with publications, awards, and the ability to secure increasingly competitive funding grants (Panaretos and Malesios 2009; Lacey et al. 2015; Finkel 2019). This also points to the need to better understand both research and innovation system level mechanisms for enabling transparency that will occur at and across organisational scales and how individuals will operate within and assess the benefits of these systems at the personal scale.

Openness and open access

There were 68 priority statements that highlighted the terms 'openness' and 'open access'. The analysis of this data suggests an emerging distinction between the concept of openness (to differing perspectives, values and priorities) and the concept of open access to scientific outputs as might be traditionally understood. It also suggests there are still varied understandings and expectations of these terms in the practice or experience of scientists and researchers (Vicente-Saez and Martinez-Fuentes 2018) and they continue to be conflated or used interchangeably. In distilling the differences between how the terms were used by participants, our analysis revealed that the terms most frequently associated with the narrower framing of open access tended to refer to publications, data, cost and resourcing issues. In many ways, this reflects the focus on improving cost efficiencies in the publication process (Productivity Commission 2016), which was summarised at the outset of this article. Participants were clear in their views that scientific publications, particularly those that had been publicly funded, should be made freely accessible. Furthermore, some priority statements addressed possible constraints to achieving the goal of

open access, including resourcing requirements and information sensitivities. For example:

> There needs to be a system to fund open-access publications. The high cost of open access outlets ensures a good deal of research cannot be published in a manner that is freely accessible to the public, particularly research from junior scientists.

The above quote also highlights this as a specific challenge for early career scientists and researchers, emphasising that traditional forms of professional recognition, such as research outputs, remain critical to career advancement and reward. However, this was accompanied by some caution about the need to also acknowledge when open access to all data and information may not always be the most appropriate or best outcome:

> Determine what should or shouldn't be transparent or open. Some archives contain records that were not intended for publication, e.g. sensitive, personal, commercial information. Archives must have appropriate licencing and access protocols and obligations that enable transparency and openness as appropriate.

What distinguished the priority statements that were more aligned with openness was a shift away from accessibility to research outputs and toward higher order goals such as incentives, transparency and accountability. Here the tendency was to move toward the more expansive potential of open science, or openness as described in the responsible innovation literature (Owen et al. 2013; Stilgoe, Owen, and Macnaghten 2013). What did emerge in this data was a desire to see increased transdisciplinary research valued and recognised and the inclusion of cultural knowledge, experiential knowledge and local knowledge valued and recognised alongside scientific knowledge. Finally, openness was also understood as a way of achieving greater inclusion and diversity in science and research, and there was emphasis on removing barriers based on gender and ethnicity in research and public institutions. In this interpretation, participants identified an avenue for openness to make scientific research itself more open to diverse participation as a way of generating the knowledge that would respond to multiple needs and perspectives in the world.

Media engagement

This final theme encompasses priorities concerning transparent and responsible engagement with the media. Given that greater calls for openness and transparency have highlighted a role for increased public engagement and science communication on the part of scientists and researchers, it is acknowledged that the media has a role to play in influencing how the public might interact with science (Holliman et al. 2009). While this emerged as the least dominant theme (24 statements), it is of interest as it looks at the role of those beyond the research and innovation system in enabling transparency and openness. The priorities vary from normative issues related to the nature of media engagement and responsibilities to more tangible and direct suggestions. For example, there was a clear focus on ensuring responsible reporting of science in the media, including from research institutions, and concerns that media reporting tended toward sensational claims:

> Accuracy in institutional (academic) media and press releases about their scientific research, avoiding hyperbole that leads to misalignment of public expectations versus scientific reality.

There is extensive literature on the use of media to increase knowledge about science, create more interest in science, inform beliefs about science, and contribute to higher trust in scientists (Nisbet et al. 2002; Hwang and Southwell 2009; Retzbach and Maier 2014). However, the data revealed a focus on the training and skills required; both for scientists in engaging with media but also for media, in terms of better understanding and communicating scientific studies. In this case, there seemed to be a desire to improve the nature of the relationship between science and the media, both to address perceptions that media engagement had been detrimental in the past but also where such engagement could improve the societal reach and impact of science.

Limitations and further research

As noted earlier, this research is based on a non-probability, convenience sample and therefore it is important to refer to these limitations in interpreting the findings. However, though a non-probability sampling technique was used, the demographic characteristics of the participants are still typical of those working in the Australian research and innovation system, and hence provide valuable data for understanding current perspectives on open science for responsible innovation in Australia. The nature of this research meant that gaining the unique perspectives of this sub-set of the Australian population was essential. The study was not designed to draw statistically generalisable conclusions about the broader Australian population. Rather, intended as exploratory by nature, this research provides important preliminary data on the perceptions and opinions of the Australian science and research professionals surveyed. We specifically employed a research design that targeted science and research professionals to access their unique perspectives on the Australian research and innovation system. By utilising this approach, this paper empirically contributes to responsible innovation literature and theory, and to a greater understanding of open science in the Australian research and innovation system. To that end, while the four priorities that emerged are instructive, they also require further examination and qualification. This could lead to a more effective exploration and development of models for more inclusive and deliberative governance of science in Australia, a closer examination of the perceived unmet expectations of scientists and researchers about transparency and openness, and to test the views expressed in this research against the expectations of the public in terms of the value of open science.

Conclusion

This research presented the perspectives of 171 scientists, researchers and other professionals working in the Australian research and innovation system on the role of open science for responsible innovation. Openness, open access and open science are appearing more frequently in Australia and around the world, but often used interchangeably to describe multiple benefits, both perceived and anticipated. It was our aim with this research to deliberately move beyond the narrow concept of open access and toward the more expansive goal of open science to see how such a practice might deliver greater benefit for society. We also sought to examine the extent to which Australian scientists and researchers identified and challenged their own scientific practice and institutions in advancing the broader goals of open science.

One clear finding to emerge was a gap between expectations and beliefs about current practice on the transparency and openness of scientists, research delivery agencies and research funding agencies. There was strong agreement among participants with commitment to these principles but comparatively low levels of confidence that funders were transparently communicating their decisions. These views on funding also emerged as one of the key priority areas identified by participants, revealing a belief that transparency of funding was linked to public accountability and higher levels of public trust in science, accompanied by a shared view that science is not accessible enough to the public.

While these results revealed perceptions of current practice in Australia, the participants identified their priorities for improving transparency and openness into the future. The strongest attention was levelled at the role of science outreach and transparency of funding. In relation to science outreach, there was a recognition that public engagement was important but a lack of clarity expressed as to why or how it might occur. In relation to science funding, the challenge of operationalising transparency and openness at the organisational versus individual scale was raised, highlighting the challenges associated with competition in research and the problem of individual career incentives not being aligned with generating greater public value and impact from science. Naturally, these issues have implications for the nature of resourcing, reward mechanisms, competition and organisational culture across the research sector but it also identifies a strong focus on creating greater transparency of traditional modes of knowledge creation and dissemination among those already engaged in the system. This is a useful finding as it suggests that transparency and openness are also important to building awareness of existing institutional arrangements and knowledge production modes; not necessarily to disrupting or challenging them. While there was some evidence of engaging with different forms of knowledge beginning with multidisciplinary modes and moving outward into society, there was a higher level of attention focused on open access to data and publications (again prioritising traditional modes of knowledge creation and dissemination albeit with greater transparency and wider access).

At the outset of this paper, we proposed that responsibility for enabling openness and transparency was not only the responsibility of scientists and researchers but would be necessarily shared with the broader research and innovation system, including the institutions that fund and support the delivery and dissemination of scientific research and innovation, and the media. While the engagement with media highlighted a more traditional science communication role, there is opportunity to think beyond the media as a mere conduit to the societal impact of scientific research. Specifically, our research highlights the importance of understanding the specific range of responsibilities of open science across different institutions (i.e. research implementing organisations such as universities, PFRAs and research funders and managers) (Christensen et al. 2020). The interchanging use of terminology and the focus on greater transparency within existing knowledge creation and dissemination systems suggested that the open science debate in Australia is still emergent. There is a level of familiarity and comfort with open access but a less shared view of more collaborative or deliberative modes of open science and the nature of the value that would be delivered by adopting such approaches.

While these insights have provided preliminary data on the current views and priorities on open science for responsible innovation in Australia, one aspect that was notably absent was a focus on alignment with societal relevance among the suggested priorities

expressed in the study (Rosenlund, Notini, and Bravo 2017). Here there is a need to understand the expectations of the public. Are their expectations for increased transparency and openness the same as those working in the research and innovation system? What are their expectations of how science can contribute to a better world? The real end game appears to be in understanding these questions about open science from a broader societal perspective. Only then can we begin to articulate what open science means in an Australian research and innovation context, and the kinds of activities that may help policymakers and research institutions move beyond open access and operationalise open science for responsible innovation as more than a mere aspiration.

Notes

1. As described here, open science is not the sole focus of the broader research and survey, but rather one theme among others including ethical scientific practice and the nature of the dialogue between science and society. The results of the full survey have been reported elsewhere (see Herington, Coates, and Lacey 2019).
2. The full survey instrument has been published in Herington, Coates, and Lacey (2019).

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