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Open Science and Public Engagement with Engineering

Ann Grand,[*] Clare Wilkinson,[*] Karen Bultitude,[*] Alan Winfield[†]

Abstract

Open Science is an emerging approach to the conduct of science, technology and engineering projects, in which information about the whole of an ongoing investigation is made available on and through the Internet. Adopting an Open Science approach means the audience for the research can extend beyond the researchers involved to other researchers and to members of the public. Thus, Open Science has implications for engineering research, practice, publishing and public engagement with engineering. This paper reviews the history and evolution of the Open Science movement, includes some reflections on the related areas of Open Access, peer-review and public engagement with science and engineering and discusses data gathered from interviews. The analysis suggests that interviewees have concerns about issues such as precedence and protection of original work and the time needed to integrate open science practices into daily work. Successfully working in such collaborations is likely to require not only common practical tools but also the development of shared language and understanding between researchers and members of the public. Interviewees recognise the value of Open Science in collaborative research and its innovative facility to sustain direct public access to research outputs. It also has the potential to allow members of the public to make real practical contributions to research.

Key words: open science, public engagement, engineering

[*] Science Communication Unit, University of the West of England, Bristol, UK

[†] Bristol Robotics Laboratory, Bristol, UK

1 Context

As Open Science initiatives exist through and depend on the Internet, there are few boundaries to preclude members of the public from being among those who engage with research projects that operate on 'open' principles. Open Science is therefore unusual in that it presents opportunities for direct, unmediated access to engineering projects for public audiences, raising the questions of the extent to which 'open' projects could, or perhaps should, take the public's needs into account. Some researchers are already beginning to consider how Open Science can adapt to meet the needs of these new audiences; to find ways in which all participants can value the validity and importance of each others' expertises and experiences and 'encourage and provide paths to those with enthusiasm but insufficient expertise to gain sufficient expertise to contribute effectively' (Neylon, 2010).

Open Science has the potential to be a novel engagement mechanism for projects in science, technology and engineering. The UK Department for Innovation, Universities and Skills (DIUS) believes 'there is a pressing need to strengthen the level of high-quality science engagement with the public on all major science issues' (DIUS, 2008, p.6) and that there is a public demand for 'more information directly from scientists at an early stage in the research process […] Our strategy must look for innovative ways to provide people of any age with access to scientific resources and information' (DIUS, 2008, p.8). Indeed, 'all governments have to take decisions in contentious and difficult areas, for example science, technology and national security; energy policy; sustainable development; climate change; space exploration; and nanotechnology' (AAAS, 2008, cited in McCaillie et al, 2009, p.28).

While, for a variety of reasons, many researchers believe it is 'important to engage the non-specialist public' (Royal Society, 2006, p.9) or that it is 'a duty […] because taxpayers' money may ultimately fund their research' (Poliakoff and Webb, 2007, p.247), some are wary, for example because they worry that their work will be misunderstood or misquoted or that they lack the necessary skills (Poliakoff and Webb, 2007). Because Open Science involves the sharing of 'everything – data, scientific opinions, questions, ideas, folk knowledge, workflows and everything else' as it happens (Neilsen, 2009, p.32), it provides a route for engagement that is integral with everyday work and in which information flows directly from the researchers. Such openness may involve researchers in a significant change of paradigm; since no research project runs without set-backs and detours, adopting an Open Science approach means sharing failure as well as success. Yet the sharing of failure can itself be valuable: 'At present, scientists often share only the results of successful experiments. […] Endlessly re-running failed experiments helps nobody.' (*The Economist*, 2009).

2 What does 'open' mean?

Open Science is an emerging approach to the conduct of research in which the whole of an ongoing investigation and its data are made available for anyone to follow, analyse and potentially contribute to. As an approach to the conduct of science, its philosophy has not yet coalesced and its description is evolving but, as a working definition, researchers who adopt an Open Science approach are concerned to 'promote the sharing of information, know-how, and wisdom' (OpenWetWare, 2010). The collaboratively-edited Science Commons' *Principles for open science* comprise four elements: open access to research literature, open access to the research tools used, open access to the research data and an open cyberinfrastructure (Science Commons, 2008); likewise, Fry et al. (2009) in their definition of open e-science, include the need for tools and resources to have unrestricted access and use, be free of charge and use non-exclusionary (open) standards.

There are ‘many degrees and kinds of wider and easier access’ (Suber, 2004). Since the founding of the first scientific journals in the seventeenth century, researchers have both wished and been urged to share the results of their work. Journals, conferences, symposia and workshops offer researchers rich media for communication with each other: for the category of ‘engineering’ alone, the JournalSeek database lists over 3000 journals (JournalSeek, 2010). For communication with the wider public, the mass media – newspapers, television and radio – offer researchers a platform. However, in the main, the information that comes through these media arrives after the fact; whether a newspaper article or a classic peer-reviewed paper, they are ‘effectively just [a] snapshot of what the authors have done and thought at [one] moment in time’ (Waldrop, 2008). The work published is finished and complete; this leaves what happens while it is being carried out as something of a mystery to members of the public. Advocates of Open Access argue that if research is funded from the public purse, access to its results should be open: ‘it is critical that the outputs from publicly-funded research are disseminated and shared with the widest possible audience’ (Poynder, 2008). The requirement to make published outputs available is becoming more widespread. For example, the UK’s Engineering and Physical Sciences Research Council has mandated open access publication (EPSRC, 2010). Practising Open Science takes this one step further by making not only the results of research but the process of research open.

Motivations for openness likewise vary in degree and kind. The Symbrion/Replicator projects, which are investigating novel principles of adaptation and evolution for symbiotic multi-robot organisms maintain, at least partly as a means to ‘consolidate many interdisciplinary workers’ (Symbrion, 2010), an open science discussion section on their website, along with publications and technical descriptions available for download. Widespread and accessible collaboration is central to some projects, for example, The Open Science Project, which is ‘dedicated to writing and releasing free and Open Source software’ and is made up of a ‘group of scientists, mathematicians and engineers who want to encourage a collaborative environment in which science can be pursued by *anyone* who is inspired to discover something new about the natural world’ (Open Science, 2010). The Bloodhound@university project, part of the Bloodhound supersonic car project, uses openness to support interaction between engineers and university researchers by providing university staff and students with full information from the engineering team ‘about the car, the project, the design challenges and the successes, […] current problems and challenges facing the project’ and invites users to contribute to solving these problems if they are able (Bloodhound@university, 2010).

Open Science has repercussions for components of the research process, such as peer-review. Peer-review is highly-regarded as the guarantor of quality; the ‘key means to ensure that only high-quality research is funded, published and appropriately rewarded’ (RIN, 2010, p.4). However, not even guarantees are without problems: for example, peer review has had difficulties with fraud (see for example Vogel, 2006, pp 516–517)), the rejection of otherwise high-quality work that clashes with reviewers’ work and opinions, poor quality of review and instances where trans-disciplinary work has been reviewed by someone familiar with only part of the field (Gura, 2002). However, despite problems, peer-review is likely to remain an essential component of the research process; the changes and challenges presented by the growth in web-based communication and publication have led to experiments in new forms. Some journals (for example *PLoS ONE*) have experimented with open peer-review, in which papers are deposited on a website for free comment. However, a 2006 experiment in open peer-review by the journal *Nature* concluded that despite there being ‘a significant level of expressed interest in open peer-review […] there is a marked reluctance among researchers to offer open comments' (*Nature*, 2006).

3 Public Engagement with Science, Technology and Engineering

Although it has a longer history than Open Science, the concept of public engagement is also still being refined. Poliakoff and Webb (2007, p.244) characterise it as 'communication that engages an audience outside academia', although others, for example Rowe et al. (2004) argue that public participation in (for example) agenda-setting, decision-making or policy-forming, is a necessary element of engagement. Considering it more specifically in terms of public engagement with science, technology and engineering, McCaillie et al. argue that public engagement should include (italics added):

> *Mutual learning*, allowing everyone who participates to develop new or more nuanced understandings of issues and opportunities;
>
> *Empowerment* and the development of skills for participating in civic activities;
>
> *Increased awareness of the cultural relevance of science*, science as a cultural practice, and science–society interactions; and
>
> *Recognition of the importance of multiple perspectives* and domains of knowledge. (McCaillie et al., 2009, p.12)

For example, the Walking with Robots project sought to bring together robotics researchers, science communicators and members of the public to 'increase awareness of where robotics research is heading and how they [*the public*] can contribute either as engineers or as informed citizens' (Walking with Robots, 2010).

Both the rhetoric and practice of public engagement with science and engineering are moving towards an 'upstream' model (Stilgoe and Wilsdon, 2009, p.1). Supporting a model of sustained, continuing engagement throughout the process of the research calls for 'real openness and genuine open-mindedness' (Stilgoe and Wilsdon, 2009, p.1). Such openness is sought not only from researchers but also from members of the public and requires all parties to 'revise and/or extend their routine practices of science communication to meet the requirements of a more demanding agenda' (Holliman et al., 2009, p.3). To paraphrase Irwin (2008, p.208), this could be characterised not just as the requirement to move from first-order (one-way, top-down, science-focused) thinking to second-order (two-way, bottom-up dialogic, engaged) but to third-order (multiply-framed, contextual, contended) thinking. The characteristics of Irwin's third-order grouping reflect the nature of the research process – dynamic, uncertain and tentative:

> In this situation, the public communication of science and technology both takes on new significance and faces substantial new challenges […] new possibilities emerge for forms of communication that […] open up fresh interconnections between public, scientific, institutional, political and ethical visions of change in all their heterogeneity, conditionality and disagreement. (Irwin, 2008, p.210)

Public participation in research

Alongside a growing number of research groups working under Open Science practices, there exists the allied concept of projects that promote public participation in research, (sometimes called 'citizen science'), which seek to use non-professionals as a resource. Leadbeater and

Miller (2004) defined the emergence of a community they called ‘pro-ams’; engaged, and intellectually very competent, amateurs working to professional standards. Pro-ams have long been a valued resource in certain domains, such as ‘astronomy, archaeology and natural history, where skill in observation can be more important than expensive equipment’ (Silvertown, 2009, p.1). Although there are growing numbers of ‘citizen science’ projects, they still tend to be concentrated in ecology and the environmental sciences. Silvertown gives a sample of 13 projects (which he believes to be representative of citizen science in general) from Europe and North America, all of which fall within these areas.

Cohn (2008, p.193) commented that typically, ‘volunteers do not analyze data or write scientific papers but they are essential to gathering the information on which studies are based’. However, others have made subtler distinctions. Bonney, et al. (2009) identified three major categories of projects: *contributory* – projects designed by scientists to which volunteers primarily contribute data; *collaborative* – projects in which volunteers help to refine the design, analyse data or disseminate findings and *co-created* – projects designed by scientists and volunteers working together, in which the public is actively involved in most or all of the scientific process. Field and Powell (2001) describe this last type as an approach towards public understanding of research, of engagement with a process that is not static.

The categorisation of a project is also not necessarily static: Galaxy Zoo began by using the resource of some 200,000 volunteers world-wide to classify images of around a quarter of a million galaxies photographed by the Sloan Digital Sky Survey. Having tried and failed to analyse these data by computer, the professional astronomers recruited the power of many human brains instead (‘contributory’ in Bonney et al’s classification). However, not only did these volunteers produce a wealth of valuable data that has supported publications (nine in 2008) by the professionals involved but, in July 2009, the first paper inspired and written by a group of the volunteers themselves was accepted by the Monthly Notices of the Royal Astronomical Society (Galaxy Zoo, 2009), making the project collaborative, even arguably co-created. There are also examples of projects entirely created by and involving only amateurs: Diybio.org aims ‘to help make biology a worthwhile pursuit for citizen scientists, amateur biologists, and DIY biological engineers’ whose ‘home laboratories have a worldwide scope via the Web, which serves as a space for the dissemination of projects and the exchange of knowledge and techniques’ (DIYbio.org, 2009).

4 Research questions

The research reported in this paper is informed by two related questions:

i) What are the views of researchers, members of the public and other parties on Open Science's principles, methods, values and benefits and the implications and potential of open science practice for public engagement with science, technology and engineering?

ii) How might Open Science improve public engagement with science, technology and engineering?

Research method

The research has followed a grounded theory approach (Strauss and Corbin, 1990), with data collected from interviews and case studies. The early interviewees were selected as representing fields likely to offer useful insights into the research area; the analysis of the results of their interviews enabled the identification of appropriate future interviewees as gaps in the data and fruitful avenues for exploration became apparent. Interviewees have been selected through a combination of snowball sampling,[‡] convenience sampling[§] and self-selective sampling. The combination of these techniques allows for the best use of the people available and the gathering of authentic views and experience within the constraints of relatively small communities. To date, seventeen interviews have been conducted with self-identified open scientists, researchers in public engagement, amateur and professional public engagement practitioners, education professionals, amateur scientists, journalists, researchers in Open Access and members of the public.

The research protocol was approved through the researcher's university's research and governance system. A point of departure from conventional practice was that, in the spirit of 'openness', interviewees were given the choice of whether to be anonymous or whether to allow their names and other identifying factors to be disclosed as part of the process of dissemination of information. All interviews were conducted by the researcher either in person or by telephone, digitally recorded and transcribed. The interviews were semi-structured and lasted between 40 and 45 minutes. An interview guide was developed, with variations for individual interviewees, according to their area of expertise: questions were asked about the nature of the work (either voluntary or professional) carried out by the interviewee or the nature of their general interest in science (as appropriate); their opinions and practice of public engagement; barriers to understanding and engagement; understanding of the concept of Open Science and technologies used in the research process.

Consistent with grounded theory, the data analysis was emergent and inductive, 'developing categories from the data through constant comparative analysis' (Denzin and Lincoln, 1994, p.214), rather than determining coding categories before analysis. Data from the first four interviews were analysed manually to identify major themes and then re-analysed using a standard software package (Nvivo8), to deepen and extend the coding frame. All subsequent interviews have been analysed shortly after completion. To increase reliability, a selection of interviews has been re-coded by the researcher and by a colleague unconnected with this research.

‡ Targeting one member of a population (often but not always a difficult-to-reach group) and asking them to connect the researcher with another member of the group, then asking that new member to do the same until the sample is complete (Denscombe, 2005, p.16)

§ Using readily-available participants, such as people already known to the researcher, members of the research team, colleagues, etc. (Denscombe, 2005, p.16)

Findings

Factors supporting an open approach

Open projects have largely been designed as effective ways for large and multi-national research networks to share methods, information and results and allow new ideas to emerge. However, interviewees described their additional value in bringing researchers together:

> *We have Principal Investigators running at five or six different universities; data sharing is going to be an inevitable issue, so let's do something where we can all benefit and everyone else can benefit by proxy*. Beck (open scientist)

Although researchers may be used to collaborative working, taking an open approach can productively challenge established ways of working. However, interviewees recognised that for the approach to flourish, certain factors need to be in place, such as the need or desire to work collaboratively and the existence of good communication and connexions among researchers:

> *You find scientists don't do things the same way … which is an obvious thing to say but I don't think even scientists realise it some of the time until they actually sit in a room together and are challenged by their own ways of thinking.* Holliman (public engagement researcher)

> *The most tangible benefit of working openly has been finding collaborators who also feel strongly about working openly. Since people will see all the data it makes it harder to hype results […] keeping people more honest and facilitating collaboration*. Bradley (open scientist)

Interviewees recognised that as well as the 'carrot' of improved collaboration and communication, there can also be a 'stick' in the form of funders' policies. For example, the co-ordinating body for publicly-funded research in the UK, Research Councils UK (RCUK, 2009) is 'committed to the guiding principles that publicly funded research must be made available to the public and remain accessible for future generations'. However, interviewees did not necessarily see this as punitive but rather as a responsibility on the part of publicly-funded researchers to share their work with the ultimate providers of those funds:

> *If you are receiving public funds, then I think there is an obligation upon you to somehow engage with the public who are funding you.* Murcott (science journalist)

> *We need to demonstrate impact. We have paymasters; that is, the public …* Beck (open scientist)

Methods and tools supporting openness

As well as shared practical tools (wikis, repositories, data tagging, blogs, social networks, etc), interviewees noted the need for a shared ethos and behaviours:

> *What you need as well as the technical fix is, of course, all the social practices that sit around it. I think you're much more likely to get collaborative work across datasets when you've got people who already trust each other – have worked together in the past, or know each other*. Holliman (public engagement researcher)

For researchers working in the same office or lab, these social practices emerge by default but for widely-separated groups, implementation may have to be more explicit:

> *Trying to provoke a sense of community among a dispersed group of academics who haven't met each other is really hard. […] It helped that […] we'd explicitly*

> *vocalised and talked about was what sort of culture and community we wanted. Not necessarily set any guidelines; just raised the issue and raised the idea that it could go very badly wrong and that we couldn't afford it to.* Sanderson (public engagement practitioner):

Some interviewees noted that researchers may need to develop new attitudes to their data and results; accepting that research isn't perfect, merely perfectible:

> *You have to accept that reporting science in real time is not always pretty. Do your best to avoid and correct mistakes as soon as possible but mistakes and ambiguous results will happen on the way to completing any scientific project. […] Don't wait for the perfect technological solutions before starting to share.* Bradley (open scientist)

Open Science offers both scientific and public audiences the opportunity for direct, unmediated access and engagement with science. None the less, almost all the interviewees suggested there would be a need for the development of a narrative or some form of mediation for public audiences of what may be quite complex data:

> *Narrative is utterly, utterly essential. The raw data […] it's huge numbers of 1s and 0s. You cannot do anything with it. It needs to be processed; it needs to be dealt with. And once it's processed into a scientific form, it then needs to be contextualised and processed into a form that has the basic content but removes the technicalities that are barriers to comprehension.* Murcott (science journalist)

> *You do need some level of mediation, I think, unless you* [the user] *have the skills to sift it yourself.* Holliman (public engagement researcher)

However, interviewees recognised that the creation of narrative takes time on the part of researchers:

> *It can be difficult to persuade people to take time* [to write a blog post] *because you don't see how it can get built into your standard work pattern*. Neylon (open scientist)

Factors mitigating against openness

Although some argue that 'Openness is arguably the great strength of the scientific method. Through open examination and critical analysis, models can be refined, improved or rejected' (Neylon and Wu, 2009, p.540), others see hazards in placing unreviewed, unmediated data in public view and open to speculation. '[There are] dangers from […] mixing of contexts for discussions among experts and pedagogical discussions with lay people; weakening of the roles of accreditation, reputation and authorship in disciplining scientific discourse' (Smolin, 2008). This point was mentioned directly by interviewees:

> *The balance – if there is a balance to strike – is how do we protect this data; do we take this data away from everybody else so that we don't give it to the minority who are possibly going to abuse it?* Beck (open scientist)

Commercial and legal problems were also often mentioned. Legal constraints such as patenting and protection of intellectual property are 'important ways to ensure a fair return […] for investment' but they 'conflict with the principle of the free and rapid sharing of human knowledge' (Cribb and Sari, 2010, p.10). This perception extends beyond the professional research community:

> *Universities and other research institutions often require employees to sign waivers giving up financial rewards that may result from their discoveries. The royalties*

from patents on vaccines for certain communicable disease could conceivably run into the hundreds-of-millions of dollars. [...] I do not believe that universities, research institutions, and established scientists will easily move towards the 'open science' idea. Anonymous 1 (amateur scientist)

Researchers can be tied into the paradigm of secrecy, even though an open approach may bring greater rewards:

> *If you accept the argument that it's knowledge and information that are key to the knowledge economy – that they are important things, where the innovation's going to happen – then you have to accept the argument that you will become commercially more competitive by taking an open approach. But there are strong disincentives to that – the strongest one being intellectual property*. Neylon (open scientist)

While shared values were seen as important for the practice of open science, the lack of shared language is seen as an issue:

> *The issue of language and jargon [...] how you're going to make sense of a technical area in ways that are understandable to everyone. But technical language – 'specialised' language might be an easier way of talking about it – goes both ways*. Holliman (public engagement researcher)

> *Here is a bunch of people with specific domain knowledge that speak specific sets of dialects and can converse with each other. And there are other people, who speak their own sets ... have specific domain knowledge and speak specific dialects. All of them don't understand each other*. Neylon (open scientist)

For some, lack of shared language may extend into lack of shared understanding:

> *I can also imagine, for example, reading the* [laboratory and experimental] *notes and not being able to understand them fully because they'd just been written for the person themselves ...* I *understand my notes; who else cares?* Foster (science café organiser)

For academic researchers, there are worries about peer-review, precedence and acknowledgement. For many researchers, anonymous peer-reviewed publication is the 'invisible hand' that 'maintains the quality' of science (Harnad, 2000), while Jasanoff (2003, p.228) argues that: 'policy-makers, especially in the US, often spoke of [it] as the best means of validating scientific knowledge'.

> *There are ethical questions ... this is one of those heritage bugbears that are similar to the ones you get asked about doing open science – what happens if someone steals my research and publishes it before me?* Beck (open scientist)

> *I think that ... certain areas of science would run a mile before they did that* [Open Science], *they really would – because they'd see their work being compromised or they'd have real concerns about it being used without their permission or without the correct acknowledgements.* Holliman (public engagement researcher)

It's unsurprising that researchers fear being 'scooped', but practitioners argue that in many ways, Open Science offers greater safeguards than traditional methods. For example, every posting to a wiki is automatically time-stamped, providing rather better protection than a traditional laboratory notebook:

> If someone actually did try to scoop you, it would be very easy to prove your priority – and to embarrass them. I think that's really what

> is going to drive open science: the fear factor. If you wait for the journals, your work won't appear for another six to nine months. But with open science, your claim to priority is out there right away (Bradley, cited in Waldrop, 2008).

Open Science as a tool for public engagement

Although many researchers participate in public engagement activities, for members of the public, or those outside the professional research community, it can be difficult even to meet or talk with researchers:

> *I have tried on various occasions to engage in face to face conversations with the mathematicians, physiologists, philosophers and physicists, but the results have lacked depth and substance. Usually, after I introduce myself and begin discussing my ideas, invariably their first words are, 'how did someone like you ever get interested in this subject?'* Anonymous 1 (amateur scientist)

Open Science sites, because they can potentially be read by anyone, can promote such interchanges. De Roure et al. (2008, p.1) note that visitor numbers to their 'myExperiment' website (8500 between January–July 2008) are much greater than the number of registered users (1000+), which they suggest implies their site has an audience beyond researchers. However, interviewees noted there may be issues of understanding:

> *The public may sometimes not understand the science they have access to – as access does not guarantee comprehension of what is available.* Nason (amateur scientist)

Although interviewees noted the potential in open approaches for members of the public to contribute to the research process, for it to be genuinely rewarding, researchers may have to be willing to relinquish some of their control, while members of the public may have to come to terms with the unfinished, dynamic nature of research:

> *Some people are going to find that very frustrating because scientists are not suddenly going to relinquish the reins on all their work. And they shouldn't. Why should they? But they may at some point have to take on board some of the criticisms and concerns of publics.* Holliman (public engagement researcher)

> *People have this view of science that it's all a finished product that's being read down from on high, when in reality, science is a complex human institution.* Raddick (public engagement researcher)

However, even when these caveats are taken into account, openness was seen as having the potential to excite, educate and inform and even to change research:

> *An educated, scientifically literate public is an empowered public; one best suited to deal with the mounting challenges that technology undeniably thrusts upon us all. … It's a big job but one that will ultimately benefit us all.* Nason (amateur scientist)

> *… their number one reason for participating in Galaxy Zoo is they want to make a contribution to science.* Raddick (public engagement researcher)

> *… there would be a chance that a member of the public could do the analysis. And if they saw something before the scientists did, that would be a big bonus for everyone.* (Anonymous 2, science café participant)

5 Conclusion

Practising Open Science can support and sustain collaboration among researchers in large, even multi-national, networks, encouraging honesty among collaborators and with the wider public. Open Science has the potential to be a new model for direct public engagement with science, engineering and technology. Because its systems exist through and depend on the Internet, not only are its access technologies presently innovative but they are likely to remain so. Our research clearly suggests there are factors supporting an open approach to research, as well as mitigating against it. While researchers have concerns about the maintenance of reputation, precedence and acknowledgement and the protection of intellectual property, practising Open Science could enable the development of shared language, shared social practices and a shared context for complex science and engineering between researchers and members of the public. While our interviewees were primarily scientists and public engagement researchers, rather than from an engineering background, we consider that our findings apply equally to engineering, especially engineering research. Sustaining public engagement through opening up research to a wide audience has the potential to harness the power of many minds and to allow not only researchers but also members of the public to contribute to the creation of scientific progress.

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