In an urge for the possibility of science becoming more “open”, an increasing number of scientific researchers are turning to web-based tools to publish their research papers, data, workflows, and even preliminary results. Open science increases the extent to which researchers share useful (but not generally traditional-journal-worthy) information (Holden 2013), and opens more opportunities for both critique and collaboration in science. However, it is limited by a lack of understanding on creating motivation for participation. This paper studies what would provide incentives for scientists to participate in open science, and how we could maximize these incentives to encourage users of open science tools to get more involved. In short, contributions to open science should be recognized, credited, and valued. A combination of intrinsic, reputational and extrinsic incentives must take place in order to achieve success of open science.

Introduction

Science should be transparent: its workflows, claims, data, and analysis should be public to facilitate reanalysis, critique, and reuse (Nosek et al. 2012). The more data is made openly available in a useful manner, the more efficient scientific process becomes, to the To facilitate the incorporation of would-be contributions to open science To facilitate the incorporation of would-be contributions to open science of society. The journal system of scientific publishing, which currently plays a key role in academic research and career success of scientists, has many limitations that prevent it from achieving public data sharing and therefore research transparency (Nosek et al. 2012, Molly 2011). In response to these limitations, multiple groups and organizations are engaged in building web-based tools enabling researchers to share useful information that is not generally worthy of publishing in journals (Holden 2013). The concept "open science" is becoming a mainstream trend for many scientists, publishers and funders (Molly, 2011). However, barriers to achieving widespread participation in open science remain due to a range of socio-cultural reasons. Despite the fact that many people believe open science is a good cause, there is presently a lack of incentive structure that encourages scientists to share their research materials online. In an investigation of current landscape of organizations promoting open science, Holden has noted that there is much more organizational activity on the "building tools and platforms" front than on the "changing incentives and advocating for better practices" front. Study of incentive structure in the context of open science has been much neglected, but is crucial for both advocacy of open science practices and sustainability of open science community. In the light of social benefits[1] for promoting open science, this study seeks to fill the gap of understanding in the incentive structure for open science. We ask important questions such as: What might help create incentives for scientists to participate in open science? What the new scientific reward system will be like in the context of open science? How should open science contributions be recognized, credited, and valued? What should be focused on in future development of open science tools? Through discussion of potential strategies for forming incentive structures in open science, it becomes clear that a combination of intrinsic, extrinsic, and reputational incentives should be considered during development of web-based open science tools.

The scientists' mindset

We open our discussion by first looking at the personal experiences of two researchers. Samuel Moore, a Ph.D. student researching the effect of open science practices within humanities, thinks that scientists are reluctant to share data because they want to "maintain a competitive advantage over their peers":

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[1] Nosek, Brian A., Jeffrey R. Spies, and Matt Motyl articulated a convincing rationale behind the open science campaign in their paper "Scientific Utopia: II. Restructuring Incentives and Practices to Promote Truth over Publishability" (2012). They argued that opening research data and workflows would inspire and enable scientists to replicate other scientists' research results, which is an essential step towards the ideal that we accumulate only accurate scientific knowledge.

In his book *Reinventing Discovery: The New Era of Networked Science*, Nielson, "we should aim to create an open scientific culture where as much information as possible is moved out of people's heads and labs, onto the network, and into tools which can help us structure and filter the information. This means everything – data, scientific opinions, questions, ideas, workflows, etc." Nielsen provided an ample of examples that highlighted the usage of Internet tools for successful collaborative work in academia and demonstrated great potentials to improve how science is done with these online tools.

Liz Lyon wrote in *Open Science at Web-Scale*, a comprehensive consultative report that "the proliferation of social Web tools has facilitated a more collaborative approach to both big and small science, enabling globally distributed teams to work together, share data and documents, discuss experiments and publish results."

> I recently spoke with a public health researcher who told me that she wouldn't share any of her data until she had completely exhausted its potential for publications, which could take years. After that, she admitted she would have probably moved on to other things and the data would be forgotten about. Whilst this anecdote reflects the practices of only one researcher, I suspect that it reflects common practice for many researchers. (Excerpt from OKF Open Science Working Group's blog: *What Are The Incentives For Data Sharing*, by Samuel Moore, November 5, 2013.)

In her essay *Open Science? Try Good Science*[2], Maryann E. Martone, a professor in the Department of Neurosciences at the University of California, San Diego, and the Principal Investigator of the Neuroscience Information Framework, attests that the anecdote Moore mentions is a common phenomenon:

> The current mode [of doing science]: publish findings in high impact journals that only become open access after a year, make sure no one can access or re-use your data, publish under-powered studies with only positive results, allow errors introduced by incorrect data or analyses to stay within the literature for years. (Excerpt from blog: *Open Science? Try Good Science,* by Maryann E. Martone, April 2, 2014.)

When Martone speaks to her own experience with open science, she admits that she is driven by the moral good to practice a better way of doing science, but there is currently no direct reward for her to share data:

> I try to practice Open Science…although I am not immune to the allure of prestigious closed journals. I do blog, make my slides available through Slide Share, and upload pre-prints to Research Gate…I do benefit when others share their data, as I build my research these days on publicly shared data…But do I support Open Science because I am a direct beneficiary of open data and tools? No. I support Open Science because I believe that Open Science is Good Science. (Excerpt from the same blog above.)

Historically, scientific data has not been openly available because technological barriers as paper and PDF documents are not an efficient form of sharing datasets (Molly 2011). Even as the Web has opened up possibilities for efficient sharing of research

[2] http://exchanges.wiley.com/blog/2014/04/02/open-science-try-good-science/

discoveries, from the two narratives we can discern that there is a cultural reluctance to publish research materials openly, for reasons from researchers' fears about releasing data "into the wild" where they may be exploited, to a lack of incentive or recognition for doing so. A report by the Research Information Network (2008) found that some researchers were particularly opposed to sharing datasets where they felt they could extract multiple publications. In response to these issues, the rest of paper will examine how we should be able to structure the intrinsic, extrinsic, and reputational incentives for practicing open science, to provide some tangible rewards for researchers to open up their research materials for the broader community.

Intrinsic motivations

Software usability facilitates scientific discovery

Scientists are engaged in research activity by the intrinsic satisfaction of solving the "puzzles", creative activity being its own reward (Hagstrom, 1965). As such, to provide intrinsic incentives to scientists, platforms providing software support for data sharing should maximize their functionality in facilitating scientific discovery and augmenting the joy of scientific discovery. Scientists should be able to find the web-based tools able to help them become more productive researchers, thus having pleasure of using these tools. On the "building the tool" frontier, a handful of tools[3] have sprung up around open science practices and have kept growing their user base. However, according to a slight amount of discussion among scientific researchers on Internet

[3] Examples of Open Science tools becoming mainstream include: ResearchGate (www.researchgate.net), academia.edu (http://www.academia.edu), figshare (http://figshare.com), and Mendeley (http://www.mendeley.com). A list of emerging tools for open science can be found at http://science.okfn.org/tools-for-open-science.

forums, available open science tools have achieved only a limited level of usability[4] and researchers are more inclined to use a range of web tools not specifically designed for open science. For example, one researcher may use Dropbox for file syncing across devices, upload pre-prints to Mendeley, manage project source code on GitHub, upload presentations to SlideShare, and have a YouTube account to share video tutorials. As such, researchers' scientific contributions are often scattered around the Web, and they find it hard to manage these tools for their daily use and create a coherent whole as their research profile. One possible improvement for the open science tools is to integrate them with other tools that scientists use. We can find out which online tools are popular among scientists and make them inter-connectable within the infrastructure of open science platforms, thus create an online personal research center for researchers to facilitate their management of projects, discovery of interesting problems, and communication with other researchers. As this could be one compelling feature to scientists, many other possibilities exist, which requires organizations to resort to user opinions to find out what features they have yet to develop would create most productive research experience. Software usability will be the foremost reason for scientists to support open science and spread the word of a particular open science tool, which ensures that open science community sustains by active users and grows new users. Creating software that adds value to scientists' research activity and empowers them with more research capabilities is a key to form intrinsic incentives.

[4] As one user commented in a forum discussion thread, "many tools we have not yet achieved acceptable level of usability. Mostly, I would like all those tools to become more inter-connectable." https://www.researchgate.net/post/Which_online_tools_do_you_use_for_open_science.

Reciprocity in Action

A consultation of psychological literature suggests that people feel the social obligation to reciprocate when they perceive a favor is done onto them. In the software industry, largely based on principle of reciprocity, software developers give out software for free to the broader community[5] under open source licenses[6]. Reciprocity can help guide people to create a self-regulating community, as illustrated by the open source community. What does reciprocity mean in scientific research? A typical situation is as Martone has mentioned in her blog, she "benefits when others share their data", as she "builds her research these days on publicly shared data." The reciprocating ties among researchers can happen through collaborating on a same project, or in a broader sense when they simply give back to the community through opening up their source files to public for review and extension. Further, reciprocity entails everyone holding to the same standard (Peng 2013). For example, under the Reciprocal Public License (RPL)[7] for open source software, it is required that, anyone who makes use of software covered under the RPL in their own software, must also publish their software under the RPL. This clause ensures that developers cannot take advantage of the efforts of the open source community without also giving back to that community. As explained by the RPL, while there is a certain freedom in the model of free licensing, it would be "unfair to the open source community at large and to the original authors of the works in particular", if

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[5] *Open-Source is a Gift*, by Francois Zaninotto, http://redotheweb.com/2011/11/13/open-source-is-a-gift.html. Accessed April 27, 2014.

[6] For more information on open source licenses, visit the website of the Open Source Initiative (OSI), a regulatory body for Open Source Definition, with which open source licenses comply: http://opensource.org/.

[7] http://opensource.org/licenses/RPL-1.5, developed by OSI

“valuable derivatives were not consistently finding their way back into the community where they could fuel further, and faster, growth and expansion of the overall open source software base.”

A hypothetical case in the context of open science that Peng has pointed out should be a good example: imagine a rigorous research is published online with its source code and data also available on the Web for reproducibility. Then some other researcher obtains the data and code, analyzes it, and publishes a note on the Web stating that some results in the original study are ineffective or there is one important conclusion missing from the original study. He may also publish a significant paper based on this finding. If there is not a standard for this responding researcher to also make his research reproducible, it will be not fair to the original investigator. Therefore open science licenses with a clause requiring the responding researcher to contribute to open science too should be developed and enforced, in order to have everyone hold to the standard of scientific conduct. Similar to open source community, this type of license can be created and maintained by a community-recognized organization in open science, who is also responsible for revising the terms and conditions regularly to close unforeseen loopholes.

Reputational incentives

Proper credit allocation

The norm for accrediting reward to scientific contributions is principally based on recognition by fellow scientists (Merton, 1968). As Mulkay and Turner (1971) put it, recognition “is the primary reward within research communities in the sense that other rewards such as promotion, research funds and salary, are graduated in accordance with the degree of recognition received". Scientists engage in the production of new knowledge in order to obtain the professional recognition from their peers, in the form of references to their work in the literature, honorific awards, and institutional positions of stature (Gustin, 1973).

Merton has pointed out the existence of Matthew Effect in science, which is construed as the issue of misallocation of credits to scientists in the traditional scientific reward system that is publication-based due to some psychological processes. One pattern is that in papers coauthored by researchers with unequal reputations, recognition tends to be skewed in favor of more established scientists. Most readers tempt to notice the names they are familiar with, therefore creating a virtual anonymity of junior researchers. If a junior researcher is considered for a job by people having not known much about him, and if he has published together with some known names, it naturally makes people ask how much his own contribution really is. Further, when a scientist of high reputation introduces a scientific contribution, it will usually have greater visibility in the scientist community than when someone having not yet made his mark does so. For example, when scientists locate pertinent research literature, one cue they use is the professional reputation of the authors. As a result, the reward system tends to allocate to more established scientists a disproportionate amount of credits for their research and has an adverse effect on careers of junior scientists. The history of science abounds in instances of essential papers written by comparatively unknown scientists, only to be neglected for years (Merton, 1968).

Open science may be able to disrupt the existing reward system in science by increasing visibility to scientists' contributions. The open science frameworks will demonstrate the entire flow of ideas, with each author's the contribution easily traceable. Therefore junior researchers, as well as researchers from less prominent institutes, will find there is a lower barrier (thus more incentive) to contribute to science and get credit for their contributions. In practice, to ensure that researchers are formally credited for their contributions we need to implement a standardized mechanism for citing open research-related files. There is an ongoing effort organized by CODATA Data Citation Standards and Practices Task Group[8] to examine a number of key issues related to data citation and promote common practices and standards in the scientific community. Other options exist for citing research materials that are not conventionally published. For example, the Open Science Framework has a novel citation type – forks – to allow researchers to reference to an entire published research project (Nosek 2014). Nevertheless, citation for open data and other research materials is an undeveloped concept and a robust citation infrastructure is to be fully worked out (Moore, 2013).

Novel scientometrics

In current scientific reward system, academic reputation of scientific researchers is primarily measured based on journal publications, with important indicators such as publication counts, citation counts, h-index, and impact factors. However, such indicators for scientists' credibility and individual accomplishments are considered flawed by

[8] Website: *http://www.codata.org/taskgroups/TGdatacitation/.* Their report: *Out of Cite, Out of Mind: The Current State of Practice, Policy, and Technology for the Citation of Data* examines the issues of citation in more details, available at https://www.jstage.jst.go.jp/article/dsj/12/0/12_OSOM13-043/_article

many[9]. As Iiad Madisch, a researcher from Harvard University and founder of the social research-oriented site ResearchGate has noted,

> For years scientists have complained about how their reputation is measured. Some methods do not reflect and do justice to individual achievements. A good example is the JIF. This is the ratio between the citations of a journal and the sum of articles published in this journal in the previous two years. The JIF is issued by Thomson Reuters yearly, and is meant to serve as an indicator for the prestige of a journal. Instead it is often used as a proxy for scientists' reputations. Even Thompson Reuters cautions against using the method as a point of reference for individual accomplishments. The company writes on its website: "Again, the impact factor should be used with informed peer review. Citation frequencies for individual articles are quite varied." Nevertheless, the JIF is widely regarded as an indicator for scientists' credibility. For instance, most German medical faculties require a certain number of JIF-indexed papers from postdoc applicants (Excerpt from blog post: *ResearchGate's RG Score and what it could mean to science*, by Dr. Ijad Madisch on Dec 20, 2012)

More note-worthily, journal-based indicators almost only take authorship of papers into account as "scientific contributions", regardless of other types of beneficial research activities. Gezelter (2012) has noticed that when a scientist builds a hobby project[10] that is useful to the scientific community, there has never been commensurate recognition of these contributions in the form of citations in the scientific literature. Beneficial scientific activities that are not incorporated into current scientometrics, such as cleaning up code for release, setting up a microscopy image database, or writing a blog, do not provide effective reputational incentives for scientists to perform.

[9] See also *Looks Good On Paper: A flawed system for judging research is leading to academic fraud*. The Economist, published on Sep 28, 2013.

[10] Gezelter mentioned two projects: *Jmol,* a molecular visualization tool that is widely used in chemical instruction, journals (ACS & Royal Society), numerous proteins and materials science, and the RCSB protein databank. It has been an unfunded "hobby" project that has been passed down to 5 separate lead developers over the years. The other one, OpenMD (OOPSE), is a research code base that has been developed while carrying out funded research on other topics.

As one solution, data provided by web tools can be used to create new metrics and measurements for a researcher's scientific contributions. In particular, open science tools have the potential of providing novel avenues for a scientist to gain reputation for not only publishing papers, but also other types of research-related contributions they make. With proper design and software development processes, open science tools should have the ability to aggregate data about user contributions from researchers, within open science community or from online communities elsewhere (if researchers link their other accounts to open science accounts). Once scientists start to routinely use open science tools to manage and publish their research efforts, web software would collect their data in large quantities and various domains, and provide a more comprehensive measurement on their research activities than the journal-based system. The open science tools offer opportunities to record diverse types of research activities, but it is up to the community to reward them with appropriate recognition. Although it still requires time for metrics as such to be fleshed out and take ground in open science community, Web 2.0 tools are promising in giving scientific researchers more opportunities to get their various contributions recognized.

It is vital to note that developing novel scientometrics based on software usage is a challenging task, and that since open science tools have not been an integral part of research routines for many scientists, introducing such metrics to public needs more caution. In 2012, ResearchGate introduced a reputation metric called the "RG Score" based on data gathered from site usage. Intended to replace the traditional publication and citation counts, the computation of this overall reputation index is claimed to involve "every step of the research process". However, a recent study has pointed out that the

“RG Score”, failing in journal impact factor calculations, is “deeply flawed” (Tausch, 2013). Since release, users of ResearchGate have many negative opinions about the “RG Score” as a reflector of their real contributions[11], mostly because the score is believed to put emphasis on user communication and interactivity, while not paying much effort to discern the quality of comments. As a result, the “RG Score” is generally not taken seriously among scientists, if not ridiculed.

This incident highlights the challenge of designing scientometrics for open science. What sort of data should be included in the computation of a scientist’s reputation? How should we tie in a scientist’s contribution level to his reputation? Should we attempt to assign a score to scientist or simply display his impacts in some storytelling way? Designing novel scientometrics should be a rigorous process, in which detailed explanations about the new indicators should be accessible to public, and their logic rigorously defended. These novel metrics should be molded by opinions of the greater science community. As pivot user opinions accumulate about new indicators, developers need to take efforts to analyze the effectiveness and fairness of these indicators, before releasing them. At stake is the credibility of open science community.

Extrinsic/Career incentives

A central problem to the open science incentive issue is the lack of career rewards, which makes it difficult for researchers to justify the time and effort required to make their source files available (Molly 2011). Unless incentives for career success are aligned, it is not likely that researchers will change their daily practices (Nosek 2014).

[11] User discussion thread on ResearchGate: https://www.researchgate.net/post/Does_anyone_understand_how_it_is_calculated_the_RG_score

Nielsen (2008) has pointed out that scientists have been slow to adopt online tools as a platform to practice open science. In an attempt to detect potential barrier for adopting open science, Nielson used online commentary systems for scientific papers as an example. From the failure of such systems Nielson speculated that while thoughtful commentary on scientific papers is certainly useful for other scientists, there were few incentives for people to write such comments. He further exposed the mindsets of young scientists brought to the pursuit of scientific publications and grants:

> To get a position at a major university the most important thing is an impressive record of scientific papers. These papers will bring in the research grants and letters of recommendation necessary to be hired. Competition for positions is so fierce that 80 hour per week are common. The pace relaxes after tenure, but continued grant support still requires a strong work ethic. It is no wonder people have little inclination to contribute to the online comment sites. (Excerpt from blog post, *The Future of Science*, by Michael Nielsen on July 17, 2008.)

As Nielson has discussed, researchers do not have incentive to make open contributions because these activities do not have a direct impact on their career trajectory. For effective change in behavior to happen, we must create more incentive in the hiring process of researchers so that they feel some payoff in their career for making open science practices routine of their daily research.

Raymond (2002) has drawn an interesting parallel between academia and the hacker culture in computer industry in that they [presumably] both fit a reputation-game gift culture, which is considered as an "optimal way to cooperate for generating high-quality creative work globally". A case in point from the software industry is GitHub, the most popular platform for hosting open-source software projects coupled with social networking functionalities. Originated from a web interface for software Version Control System, the site has quickly become a productive virtual community that continues to facilitate the advancement of software development around the Globe. Users of GitHub, mostly software practitioners, do not just use the site to manage their projects and communicate with their collaborators, but they also search for that next big problem to solve or just try to stay relevant with one of the hundreds of software languages and frameworks. Through voluntarily committing their software code to the site, users of GitHub gain community recognition for their skills and continuous contributions to the industry. Perhaps the biggest illustration of GitHub's importance is how hiring managers hunting for skilled software engineers choose to leverage it. With much more frequency, companies are asking candidates to submit their GitHub account information along with their resumes to see their actual work. Software job candidates can thus point to their contributions on GitHub as a testimony to their passion and skill in software development and have a much higher chance of landing a desired position.

Similar to how GitHub is changing the way that companies hire software engineers, open science websites have the potential to create a new avenue for identifying distinguished scientists and providing them with proper research positions. Researchers may have the option to use their open science portfolios as a component of their CVs and provide evidence for decision support in the hiring process of academic jobs. Notes about nature of contribution might be particularly relevant for junior scholars that need to make clear their contributions for hiring and career advancement. In this way, scholars would no longer fear that their time devoted to open science practices is meaningless for their career, but instead realize that it has a direct positive impact on their career trajectory as well. This extrinsic incentive relies on a mindset shift of scientists, funders of research, and university management to create a cultural change, and is probably the most difficult part of the cause. Ideally as a first step, open science platforms could provide a reliable evaluation system for researchers based on open science contributions. Then it follows the recognition from the wider community to accept such metrics.

Conclusion and future work

As trend towards open source communities make clear, intrinsic incentives will be the core driving force for enthusiastic researchers to join in open science. These pivot users will be willing to use the tools even when external incentives have not yet existed. A small, dedicated user base will create a culture that is similar to the hacker culture, but they will make the impact strong enough to get other scientists involved in open science practices. At the same time, organizations should create convincing reputational incentives based on usage of open science tools, in an attempt to extend the "golden standards" of current scientific reward system. Finally, cultural shift should take place to accept the new standard, and allow open science practices to have direct impact on scientists' career path. Only when a network of incentives is implemented will science community truly be ready for the new era of open science.

A world embracing open science is a world in which scientists habitually make public all aspects of their research online and extensively collaborate on, critique, reanalyze, and extend each other's work. This is a set of radically different practices from those established by the journal system that is not easily compatible with current standard. As it may have a chance to eventually replace the system of journal publishing, the open science community is still in its infancy, and given the fact that opens science values conflict greatly with scientific cultural norms, doubts and concerns of potential participants will inevitably rise. Without addressing public concerns, incentive structure would not work as effectively as we expect. For example, legal issues rise quickly in an online world where plagiarism is a serious problem, more specifically:

- How to time-stamp ideas and make sure they are not plagiarized?
- How to manage free-riders?
- How to solve the problem of intellectual property protection, including copyright and licensing issues?

Transparency in project activities will help minimize the risks and other common conflicts that emerge in collaborative research. But have a committee to establish a set of community standards and ethical code for these issues would also be desired. Another area for future study could be refining the use model for open science software to make it more compatible with scientists' research routines – that is, to increase software usability. For example, things that a scholar may ask from the open science tool may include:

- How to easily manage my projects on the website?
- How to cope with the flood of published research to find materials pertinent to my research?
- How to stay relevant with the popular projects of my discipline and select important research problems to attend to?
- How to allow other scientists to view a research profile of me, including my work history and research interests? Is it possible to incorporate a measure of scientific productivity of a scholar, based on the quantity and quality of his published research data?

And the list goes on. This kind of study could be based on both theoretical formulations and empirical investigation methods, including soliciting user requirements, conducting interviews, and software usability testing. The purpose is to know more about current norms of scientific research and the sort out a direction for development of open science frameworks that scholars collectively desire. We encourage others of the wider scientific community to join the discussion to identify the problems they face in publishing, discovering, and reusing research online, and we hope that organizations providing open science tools think in terms of creating incentives and rewards for users of their tools.

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