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Crowdsourcing the Human Gut. Is crowdsourcing also 'citizen science'?

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Abstract

The participation of non-professionally trained people in so-called citizen science (CS) projects is a much discussed topic at the moment. Frequently, however, the contribution of citizens is limited to only a few narrow tasks. Focusing on an initiative dedicated to the study of the human microbiome, this paper describes such a case where citizen participation is limited to the provision of funding, samples, and personal data. Researchers opted for a crowdsourced approaches because other forms of funding and recruitment did not seem feasible. We argue that despite the narrow understanding of participation in the context of some CS projects, they can address some of the democratic concerns related to scientific knowledge creation. For example, CS and crowdsourcing can help to foster dialogue between researchers and publics, and increase the influence of citizens on research agenda setting.

Keywords

Citizen science; Health communication; Public engagement with science and technology

Introduction. Citizen science between crowdsourcing and engagement

The concept of "citizen science" (CS), in its most frequent usage, encompasses a wide variety of participatory projects in scientific research, from online gaming to citizen-based data collection. CS is used in a large number of scientific disciplines, from astronomy to botany.[1] Partly because it is used in such a wide variety of fields and contexts, CS is a phenomenon with fuzzy boundaries. Projects subsumed under the label of CS range from initiatives started and run by citizens outside of established institutional settings to institutionally-driven projects where contributions from non-professional scientists play only a very small role, or where participants' inputs are confined to very strict and fixed formats. Haklay [2015] proposed a definition of CS that captures the heterogeneity of practices and technologies subsumed under this label: CS refers to "Participation of lay citizens in design, funding, data collection, analysis, report or dissemination of scientific research."

Some researchers decide to make use of CS approaches and tools for the fulfilment of tasks that a small group of professional scientists alone would not be able to

[1] Cf. Wiggins and Crowston [2011], Wiggins and Crowston [2012] and Wiggins and Crowston [2015] for typologies of CS.

carry out. We call this the "instrumental" rationale for CS. It is instrumental in the sense that citizen participation here is conceived as a tool to improve specific research tasks, such as effective data collection, rapid analysis, or the reliable dissemination of results. Instrumental rationales also shape the structure of CS projects that aim at recruiting the largest possible number, or a certain specific *large* number, of participants. A term that refers to forms of CS designed to obtain contributions from as many participants as possible is "crowdsourcing".[2]

There have been discussions on how CS could increase the scientific literacy of the public and other social benefits associated with public understanding of science [Bonney et al., 2009]. There is, however, a different meaning of CS that sometimes resurfaces in contemporary discussions and analyses. Explicit uses of the term "citizen science" date back to the early '90s and to studies of environmental science and policy [Irwin, 1995]. These studies described the role of lay citizens in the production of knowledge and paved the way for research (and advocacy) of citizen participation in science within the scholarly discipline of science and technology studies (STS). CS as it is understood in this strand of the STS literature pertains to issues of research agenda setting and political discussions on legitimate means and ends of science. STS scholars paid relatively little attention to hands-on involvement of citizens in research, including instrumental forms of participation and crowdsourcing that are nowadays seen as CS. Instead, STS scholars were concerned with the democratisation of science, public accountability and publicly questioning the political choices concealed in research agendas [Wynne, 1998; Wynne, 2007; Jasanoff, 2003]. CS, in this form, responds to a democratic rationale, that of bringing public deliberation into the organisation, agenda setting and even execution of science. We will refer to such aspirations as part of a *democratic* ideal of citizen engagement in science.[3] Such a democratic ideal acknowledges the importance of some of the instruments of public influence on science that are already in place, such as delegative mechanisms that empower elected political representatives in the oversight of science funding bodies and even the market, for example, insofar as these are driven by citizens' preferences and values. The advocates of such ideals, however, diagnose a crisis of the "delegative model" of research governance [e.g. Callon, Lascoumes and Barthe, 2009] and argue for the adoption of more direct forms of involvement of citizens in research practices.

These two different strands of understandings of citizen science, namely as a "crowdsourcing" tool and as a way to make science more accountable and democratic, beg the question of the relationship between these concepts. Are the two understandings compatible? Do they underpin approaches to citizen participation in science that overlap in practical terms? Can any CS project satisfy at once both aspirations, thus promoting a number of diverse social goods? And if yes, how? In this paper, we will address these questions on the basis of a specific case study, namely a CS projects dedicated to the study of the human gut microbiome. We chose the case study because the study of the human gut microbiome is currently growing at rapid speed. This is due to several envisioned

[2]The term "crowdsourcing" is sometimes used with other connotations in the scholarly literature and other materials. In this paper, "crowdsourcing" denotes the devolution of any or all parts of a scientific research project to participants without professional scientific training.

[3]The concept of engagement is broader than the scope of CS in the STS literature, and includes initiatives for the public understanding of science intended as pedagogical activities where scientists explain what they do to a lay public. See [Riesch, Potter and Davies, 2013] for a paper with aims similar to ours that employs a broader conception of engagement.

applications, for example in drug development.[4] It is thus reasonable to expect that successful CS projects in this area will be repeated and emulated in the future. Moreover, we consider this example as a relatively "typical" case of CS as it makes heavy use of democratic rhetoric, while being designed and run purely by professional scientists.

On the basis of our case study, we will show that even CS projects whose "participatory" elements are largely reducible to crowdsourcing can act as *catalyst* of democratic citizen engagement in research as defined above, in at least two ways. First, crowdsourcing can facilitate and deepen the dialogue between citizens and researchers. We will document this with examples of dialogues between citizens and researchers promoted by crowdsourcing. Second, we argue that crowdsourcing (including crowdfunding) can enhance the scope of citizens' control on research agenda setting, at least in cases where crowdfunding is not used merely to compensate for decreasing research funding from other sources. In summary, we argue on the basis of empirical analysis and theoretical reflections that crowdsourcing and crowdfunding *could* potentially prove valuable for citizen engagement in research, even if the motivations for adopting citizen science approaches in several such projects are different.

After a section dedicated to the description of our case studies and the democratic rhetoric accompanying them (section "Case study. CS and the human microbiome"), we argue that these initiatives respond to organizational needs due to constraints on research funding and recruitment; we call this motivation for CS the "Schumpeterian rationale" (section "Crowdsourcing and the Schumpeterian rationale for CS"). In section "Impact on engagement " we argue on the basis of our case study that crowdsourcing can catalyse democratic citizen engagement. We then discuss how citizens are endowed with control power on research agenda setting on the basis of crowdsourcing (section "Voting with samples (and money)"). In section "Conclusions" we summarize our findings.

Case study. CS and the human microbiome

Microbial cells residing in the human gut outnumber human cells. There is growing evidence that such microbes, mostly bacteria but also virus, fungi and unicellular eukaryotes, are involved in healthy and unhealthy development and physiology.

The genomics of the human microbiome, and especially of the bacteria residing in the human gut, have been systematically explored ever since high-throughput "omics" sequencing techniques became available. To understand the interactions of bacterial populations in the gut with human genetics and the environment, and their combined effect on human health and disease, scientists have started establishing large genomic datasets from multiple samples [Methé et al., 2012].

Efforts in the establishment of large human microbiome genomic datasets have grown in recent years, and a host of private and public initiatives are devoted to it. Academic researchers, such as those in the American Gut Project (AGP)[5] and its British offshoot, the British Gut Project (BGP),[6] as well as private enterprises, such

[4] Cf. El Rakaiby et al. [2014] on pharmaco-microbiomics.
[5] Cf. http://humanfoodproject.com/americangut/.
[6] Cf. http://www.britishgut.org/.

as the commercial startup uBiome,[7] recruit participants online. Participants are funders and donors of samples and receive personal analyses of gut bacteria in return, following the model of research projects and/or enterprises established by companies such as the Genographic project[8] or 23andMe.[9] Upon subscribing and donating money through a crowdfunding platform, participants receive by post a swabbing kit and survey that they have to fill in and return to a lab. Within a few weeks' time, they receive a summary of the analysis of their personal samples, including comparisons of personal microbiome diversity to reference analyses (e.g. vegetarian, athletes, etc.).

Both uBiome and the A/BGP collect money on the basis of "donations" from users through crowdfunding platforms[10] in exchange for a "personalised" analysis of their gut bacteria. Minimum donations are obligatory and cover handling and sequencing expenses. A/BGP is not backed by further grants or other major sources of funding, although there are some private sponsors for equipment. The crowdsourcing approach adopted by the two[11] Gut Projects obtained the following results: AGP collected USD 839,007 and recruited 5567 participants, while its British sibling BGP collected USD 31,000 dollars recruited 252 participants[12] (note that the British arm of the project started ca. 2 years after the American Gut Project). uBiome, which is the only for-profit of these three projects, collected 356,080 dollars from 2572 participants.[13]

Formally, participants have very little influence in the design or management of the project. They have no say in how samples and data are collected, analysed, or how they are used and made available to other parties. Neither are participants co-authors on papers emerging from research using the projects' data. Consequently, the A/BGP projects rank very low in existing quality scales of citizen participation in science [Prainsack, 2014] or indeed even in more general quality scales of participatory initiatives [Kelty et al., 2015].[14] Nevertheless, leading scientists and entrepreneurs of A/BGP and uBiome respectively maintain they are doing CS. The instrumental rationale of CS is obviously prominent here, but do such crowdsourcing projects deepen public influence in science or render science more "democratic"?

Jessica Richman, co-founder of the startup uBiome, is an outspoken advocate of CS and believes that the answer to such questions is a resolute "yes". In a recent TED talk [Richman, 2013], Richman claimed that "technological forces are bringing us

[7] Cf. http://ubiome.com/.

[8] Cf. https://genographic.nationalgeographic.com/.

[9] Cf. https://www.23andme.com/.

[10] The online platforms used by such projects are simple user interfaces. There are of course other platforms that enable more sophisticated forms of citizen participation and call themselves "citizen science" platforms; an example would be patient social networks such as PatientsLikeMe.

[11] We will consider BGP and AGP as a single project for the purposes of this paper, as they are tightly coordinated (and all analyses for both projects are carried out at within the same lab at AGP).

[12] Fundrazr, https://fundrazr.com/ (visited on 23rd March 2016).

[13] Indiegogo, https://www.indiegogo.com/ (visited on 23rd March 2016).

[14] Along with these similarities, there are very important differences between A/BGP and uBiome. These differences are due to their funding channels, objectives and institutional settings. They concern the publication of and access to results, methods, datasets, and analysis packages. The academic-led A/BGP generally scores better as far as openness to the broader research community and the public is concerned. These are obviously important issues, however we are mainly focusing for the sake of this analysis on the aspects that are shared by the two initiatives.

together to do science" and that CS will ultimately alter how science is done. In her view, in the near future, scientists will be mainly involved in "setting up structures to integrate citizens into science", thereby tapping into the enormous research potentials of non professionals who have so far been excluded from science. In Richman's view, people in developing countries, people who are not of "the right gender and the right skin colour", or all those "not fortunate enough" to take part in research so far are part of this untapped potential of people who could be motivated and enabled to contribute. She believes that today's elitist science would be more innovative if we turned it into a "democratised open system where anyone can participate", and participate not as "subjects or patients" but "human beings with the capacity to understand the world". In the world that Richman imagines, everybody is able "to set the research agenda" and to pursue interesting lines of inquiry.

These aspirations may seem at odds with the forms of participation that uBiome envisages for participants. Very similar to the A/BGP, contributions from participants are limited to sending stool, oral and/or genital swabs (including samples from pets) to their facilities along with personal data about lifestyle and diseases. Even if people are thus helping to "turn anecdotes into data", as Richman describes it, these forms participation are relatively simple and do not tap into the creative and innovative potential of the participants. At the same time, it remains true that, as much as in "traditional research", lay participants will not be in charge of any research project themselves and that such activities hardly deepen citizen engagement as defined above. This limitation is readily acknowledged by Richman, who readily admits that the divide between experts and lay citizens will not be bridged by CS projects such as uBiome. Concerns regarding the difficulty of bridge the gap between experts and lay people with the help of participatory methods have been raised before [e.g. Stone, 2013]. Nevertheless, CS activists and/or entrepreneurs continue to resort to such participatory and democratic language and they are able to do so without being criticized.

Our argument is that although many claims in Richman's TED talk are problematic in terms of their sidelining commercial stakes, they may nonetheless be grounded in an emerging trend that deserves attention. We will first offer some reasons for scepticism towards claims made by organisations promoting or using CS who treat CS as a strategic resource to enter the "marketplace of ideas" (and actual markets as well in the case of for profit projects as uBiome). Then we mitigate the cause for scepticism by highlighting some continuities at the theoretical and practical level between "thin" instances of CS such as crowdsourcing on the one hand, and democratic visions for public participation in science on the other.

Crowdsourcing and the Schumpeterian rationale for CS

In A/BGP and uBiome, crowdsourcing is used as a means to fund research that may not get funding from more traditional sources (ref), and in the case of uBiome, also to obtain financial profits. For uBiome, the only for-profit enterprise among the three projects, recruiting participants online also allows uBiome to collect biological samples despite lacking academic credentials and infrastructures. Crowdsourcing is a tool to obtain samples and money, that is, to raise the "biocapital" necessary for their operations [Rajan, 2006].

Startups such as uBiome are not normally able to raise capital in regular capital markets. But they can employ a range of financial instruments specifically designed for

risky investments in startups, such as funding from "angel investors" and crowdsourcing platforms — often flanked by incubators and accelerators that provide them with further strategic assets, e.g. management and networking skills. uBiome has also received funding from such dedicated investors.[15] The economic rationale for such instruments is that in their absence, some profitable businesses would be excluded from the market because entrance barriers are too high [Friend, 2015].

An additional barrier in the biotech industry is access to human samples and human participants. Collecting samples online can overcome this barrier, just like financial instruments tailored to startups can bypass restrictions of financial markets. In theory, such dedicated sources of funding and samples should foster innovation by increasing competition and hence incentives to research and development. uBiome staff are adamant that this is the theory underpinning their operations [Richman and Apte, 2013]. In the context of a debate on the ethical issues pertaining to uBiome activities, Richman and her uBiome co-founder, Zachary Apte, have complained that legal requirements for ethical approval of research on human subjects (IRB) are biased toward established institutions that can afford to pay for IRBs, thereby "stifling innovation". What they mean is that, exactly as obstacles in participant recruitment, legal restrictions pertaining to research ethics constitute a barrier to market access for startups that generates innovation-unfriendly monopolies.

We could call this explanation of why researchers and entrepreneurs recruit participants on the internet via crowdsourcing methods the "Schumpeterian rationale" for CS, after Schumpeter's [1944] view of economic activity as "incessant revolution" promoted by innovative newcomers that disrupt existing firms and productive structures. The Schumpeterian rationale is this: mainstream sources of funding and samples for research are biased against newcomers, as such sources are skewed towards established institutions, people and ideas. On the one hand, this is good: not every research idea deserves support. It could be duplicating previous work, be based on flawed reasoning, or violate ethical norms. On the other hand, the exclusion of promising but new research venues can lead to residual inefficiency. Crowdsourcing and crowdfunding could remedy this inefficiency by lowering entrance barriers to research, thus accelerating innovation and research.

While the idea of a Schumpeterian rationale for CS resonates with the business strategy of for profit startups, it can easily be extended to non profit CS initiatives. Indeed, reasons to adopt crowdsourcing models in the non profit sectors are equally based on the need to disrupt "knowledge monopolies" due to extant structure of research funding.

Scientists involved in academic-based projects do not lack credential, assets and reputation. However, they might perceive that particular lines of research that they believe are worth pursuing are unlikely to be funded. Interviewees[16] at BGP and AGP argued that it has become difficult to convince policy makers and funding

[15] Andreesen Horowitz and Y Combinator, as documented in specialized news websites [Root, 2014].

[16] We carried a small number of interviews (n=4) with research scientists and other staff at the British Gut Project and American Gut Project (December 2014–February 2015), which have been among the key sources of the argument we defend in this paper.

bodies to fund middle-scale hypothesis-free research projects, and to establish bioresources just for the sake of having them. In their view, funding is — as it were — *monopolised* at this stage by either hypothesis-driven research proposals where the potential applications (esp. clinical applications) are clearly on sight, or massive big data endeavours that have equally clear economic potential.[17] Here, the reluctance of decision-makers to fund hypothesis-free projects is similar to entrance market barriers for startups. Such reluctance prevents the setting up of projects that may prove valuable. In particular, projects that are theoretically or methodologically exotic, or projects that do not respond to existing priorities of funders, are excluded. There is much to be said in favour of this approach — not everything should be funded — but of course there could be inefficiency in such a system, and crowdsourcing could compensate for it.

The "Schumpeterian rationale", i.e. the necessity for outsiders (startups, newcomers, or established researchers with non-standard proposals) to raise funds and samples from non official sources has nothing to do with the democratic jargon that accompanies the activities of uBiome and A/BGP, nor with attempts to render science more democratic. In the remainder of the paper we will argue that even such utilitaristic and narrow employments participatory tools can improve the level of dialogue between researchers and the public, and strengthen public influence in the setting of research agendas (section "Voting with samples (and money)").

Impact on engagement

Once projects such as A/BGP and uBiome are launched, they set the stage for a number of interactions between researchers, lay citizens, and amateur scientists. Independently from the official channels of participation, opportunities for citizen engagement may thrive. There are a number of websites dedicated to the microbiome that are curated either by amateurs or professional scientists who run these sites in their free time. They write manuals for do-it-yourself fecal transplants or blog about various other aspects about the microbiome.[18] One such blog[19] is dedicated specifically to the CS aspects of microbiomics research:

> "If I were feeling a little grandiose, I'd say this blog is an experiment in CS and journalism. I think with the right tools — personal observation, self experimentation, and access to scientific research — ordinary people can make significant contributions to science and our understanding of health and disease. In fact, I think they can often be in a better position to make important discoveries than many experts."

This commitment to self-experimentation is reiterated in the dedication of the blog to the late Seth Roberts, pioneer of self-experimentation and diets. This blog is particularly interesting because it hosted a discussion regarding a report of

[17] Several initiatives have been set up to produce genomic datasets of human-associated bacteria; examples include the US National Institute of Health "Human Microbiome Project" launched in 2008, or the work of Liping Zhao's team in Shanghai at the Jiao Tong University [Li et al., 2008]. These initiatives, however, do not aim at establishing databases for future research but they have other, clearly specified goals, such as the establishment of protocols and reference sequences.

[18] Websites and blogs were retrieved on the basis of cross-links from articles [e.g. Saey, 2013] and keywords-based searches using online search engines (Google) in April and May 2015.

[19] https://mrheisenbug.wordpress.com (visited on 7th May 2015).

discrepancies between uBiome and AGP results [Saey, 2013][20] to which researchers at uBiome and A/BGP provided follow-ups on Twitter and on their official blogs.[21] Moreover, the discussion is a good illustration of the variety of expertise that such crowdsourcing projects are able to mobilise, and illustrates how forms of engagement and dialogue between citizens and researchers can emerge from crowdsourcing, including dialogues that may become a new channel for citizen engagement with research agenda setting.

A number of comments posted on the blog address biological, analytic and methodological aspects of uBiome and A/BGP. One user, revealing in-depth familiarity with the specific literature, observed for instance that "the phylum [of bacteria] is pretty much what most people will look at and they'll leave it at that. But it's confounding because it only tells half the story. And it's unfortunate because it's really at the sub-phylum level the presence of pathogenic bacteria seem to determine the disease state." Others reported that they carried out their own analysis using freely available online tools: "my official American Gut report was fairly different than the analysis I did on my raw .fastq files in MG-RAST". One user tried to make sense of the discrepancy taking into account uncertainty: "It could be that both estimates are "correct" within a margin of error. It would be important to know whether any differences are due to randomness (which would suggest that the data is not useful, at least not for individuals) or to some systematic effect such as differences in methodology (in which case the results may still be useful)." The disappointment about the reported discrepancy was high, as poignantly remarked by another user: "the core foundation of science is reproducible results. If none of this is reproducible (and how much have the services done to test themselves in this regard), we're just playing parlor games and reading tea leaves." In summary, some of the users of A/BGP and uBiome, or at least those confident enough to post their thoughts on a blog dedicated to the topic, seem to master the bases of biology, bioinformatics and/or statistics (although we are unable to tell whether they received any formal education in the natural sciences).[22]

Posted comments reveal some of the users' motivations for participation. Some users valued their participation in a project with scientific significance: "I submitted a sample to AmGut last August, and my impression was that I was submitting a sample to a research project, and donating money to further that research. The fact that they send me back information on my personal results is an extremely cool, but incidental, aspect of the project". Other users are instead more sceptical, and challenge the idea of "pure science" conveyed by promoters of these projects. It is worthy to report at length one such analysis:

> "This is supposed to be a research project but it's also a means of financing these organizations. [...] In fact, the only way these guys are able to finance themselves is through this direct patient model: you need a vast sample to

[20] Saey reported that estimated prevalence of different bacterial phyla were different in AGP and uBiome analyses of swabs taken from the same sample.

[21] http://www.ubiomeblog.com/american-gut-and-ubiome-data/ (visited on 31st October 2015).

[22] It would be important for future research to establish whether such projects are able to effectively reach populations that were previously not engaged with the specific research area in question, or whether they mostly speak to a „lay elite" who is has already been interested in the area. Such evidence will be very helpful to assess the democratic potential of CS projects.

> analyse the data. You can't simply receive financing and do this, as you need data. That's probably why this so called "research project" and the "$100 contribution in exchange for fecal analysis" became a plausible business model."

The same user is also concerned about the possible commercial motivations of promoters of CS: "there's no guarantee that they won't use the information (on an anonymous basis) with biotech companies for drug development down the road. Or they could partner with health and life insurance companies to better identify risky patient populations. There are many for-profit ventures which could arise from their data accumulation; this is probably the initial stage where such services parade as a research project on a non-profit platform." While this report is inaccurate, insofar uBiome is upfront about its for profit nature and the A/BGP excludes that they will use datasets for commercial activities, at least some users of these services are aware of the political economy of CS.

The majority of comments on the blog are dedicated to health issues. While we are not in a position to assess whether these comments are representative for the main motivations of all participants of the A/BGP, they form one element in the mosaic of motivations and interests that are associated with participation in such projects.

One user, commenting on the discrepancies between uBiome and A/BGP writes: "What is terrifying is the fact that some people may have been given false results and have therefore been given false information about their health. Awful". This is in line with arguments of professional researchers: "the providers obscure the notion of variability. They do include warnings that these tests aren't diagnostic (perhaps what 23&me should have done), but no disclaimers that the data itself might not be a good representation of your microbiome. The reports from American Gut obscure inter-personal variability. With interest in our microbiome skyrocketing and people performing risky at-home fecal transplants, the disclaimer of sample variability ought to be loud and clear" [Agapakis, 2014].

Some users posted their results online, reported self-experimentation ("embarking on a potato starch/kefir/kimchi experiment") or detailed a host of phenotypic and lifestyle information, seeking advice from peers. Indeed, feedback and recommendations were also posted: "I would think a good bit of added fermentable fiber in your diet, aka prebiotics", including general recommendations about the health value of such analysis: "I don't believe in trying to use these reports to assess health at all, but if someone has a specific health issue that they already know about or are concerned about, then it makes sense to use it as a *detective tool*". References to scientific studies backing these advices are scant but not absent. Few comments applauded researchers at the AGP for following up to their questions and concerns on Twitter. uBiome also posted methodological replies to the discussion about the discrepancies.[23]

We found a second website with analyses conducted on the bases of personal results and datasets released by the AGP.[24] In particular, one post was dedicated to

[23] http://www.ubiomeblog.com/american-gut-and-ubiome-data/ (visited on 7th May 2015).
[24] http://cdwscience.blogspot.de/ (visited on 7th May 2015).

a study of the association between migraine and gut bacteria diversity[25] and the author recommends additional data collection: "I would feel more confident about these results if there were more subjects who commonly experienced migraines and/or if there was longitudinal data (to track metagenomic profiles during intervals when migraine subjects did or did not experience a migraine)."

These online discussions show that crowdsourcing projects can mobilise forms of interactions between researchers and citizens even though they formally give little space to participation, as demonstrated by the variety and quality of users' contributions, by participants expressing a desire to take part in research, and the critical uptake of these endeavours among some participants. Importantly, scientists working at AGP and uBiome felt that they had to reply to the critical observations elaborated by participants. Researchers were also given feedback and recommendations pertaining to the research agenda. In summary, crowdsourcing *can* catalyse citizen engagement, even though the extent to which citizens can actually influence the design of studies and research questions through such informal channels remains to be seen.

What are the conditions that facilitate the democratic engagement of citizens in crowdsourcing projects? We can speculate that there must be some particular pre-conditions in place in order for such catalysis to take place. First, the catalysis is much facilitated if a CS project taps into existing areas of non-professional debate and expertise. In this case for instance, there were communities discussing the human microbiome that pre-dated AGP[26] and uBiome and expertise in biotechnologies is relatively common, in a similar manner to what it happens in ornithology CS initiatives, which can tap into the expertise of amateur ornithologist and birdwatchers. Perhaps even the employment of participatory jargon itself, even if merely strategic or instrumental, may increase the perceptiveness of professional researchers to citizens' input.

The latter hypothesis is particularly important for discussing the relationship between crowdsourcing and democratic engagement, as the participatory cultures [Delwiche and Henderson, 2013] that accompany crowdsourcing may make it intrinsically capable of promoting democratisation even if it is ultimately instrumental to other objectives. Richman's references to democratisation of science are decisively *unlike* those that are most common in the "participatory" wave of science and technology studies that we mentioned above and to a certain extent they are simply a more appealing jargon that conceal what we have called the Schumpeterian rationale for crowdsourcing. In addition, Richman openly criticizes "traditional" forms of citizen engagement in the aforementioned TED talk, putting forward the concept of a "democratised and open system of innovation" that is spiked with anti-establishment rhetoric. These anti-establishment discourses are common in contemporary online entrepreneurship and the idea of mobilising the "crowds" for innovation is indeed almost a commonplace in US, and especially Californian, tech-entrepreneurship. It is an idea supported by both popular and scholarly analyses [Shirky, 2010; von Hippel, 2005; Castells, 1996].

[25] http://cdwscience.blogspot.de/2013/11/metagenomic-profiles-for-american-gut.html (visited on 7th May 2015).

[26] Topics such as dietary health and lifestyles are prominent concerns for the public. Personal participation to AGP or uBiome may be seen as an instance of "lifestylisation" of health care as much as instances of public participation in research.

Why is it the case that the concepts of open systems of innovation, crowdsourcing and democratic engagement are so easily conflated? Physicist and science writer Nielsen presented a simplified model of why "open systems" may speed up discovery and innovation [Nielsen, 2011]. To tackle any complex problem x that is composed of sub-parts y_i, we can either set up a small research *team* of experts or recruit openly among the *crowd*. By definition of "expert", any expert within a small research team is better placed to solve any of the y_i sub-problems than a *random* member within the "crowd". However, for each y_i there will be in general at least one member of the crowd that has got a better idea than any of the members of the expert team (provided that the crowd is large enough). Before the advent of networking technologies, this fact was not *practically* important: transaction costs involved in aggregating "lay" expert judgment were huge, since the search for lay expertise was inefficient. Hence expert teams were systematically more efficient (fast) in solving problems such as x than any system of innovation open to the contribution of uncertified experts. As the cost of networking people decreases, we may reach a tipping point where open systems become more efficient than expert teams. This is very unlikely in scientific disciplines that require time-consuming formal training, but it is less so in applied fields where technology users and lay people master relevant local knowledge, e.g. patients suffering a rare disease.

By presenting the rationale for open innovation using the imaginary of common citizens replacing expert elites in research (as much as in other social cooperative endeavours), scholars of innovation, entrepreneurs and internet activists are able to appeal to democratic values. References to such values resonate with discourses of citizen engagement in science insofar as the latter also criticize the idea that research ought to be conducted by elites of experts. Scientists and other CS organizers that rely on such discourses cannot retrench in expertocratic practices if they are to defend their credibility as promoters of "open science", and in this sense they may be in general more receptive to the input of the public. Such relationship between crowdsourcing and citizen engagement may be weak, as it is mediated by scientists' beliefs and attitudes. However, this should be added to the intrinsic capacity of crowdsourcing to extend, albeit marginally so, for the moment, citizens' control on research agenda setting.

Voting with samples (and money)

We have argued that one reason for researchers to opt for crowdsourcing is the perception that their chances of obtaining funding through other channels (public funding, private investments, etc.) are small. We have seen that this could happen in the case of newcomers or in the case of research that is pioneering and/or does not comply with mainstream understanding of good research methodology, accepted theories, and/or good scientific questions. To ensure that resources are not wasted on projects of poor quality, both public and private funders review funding proposals, either formally or by voting with their wallets. There is the chance that (whatever the details of the assessment systems) some valuable projects are sieved out. In this sense, crowdfunding might offer a second chance to some valuable projects that would have been excluded. If so, crowdfunding might increase the overall efficiency of research funding structures. A parallel argument can be made for biological samples, which we have seen above is the second key form of "capital" that enters research projects. But does crowdfunding and, more generally, crowdsourcing enhance the *democratic* character of research in line with the ideal of citizen engagement that we outlined above? And if they do enhance the

quality of research agenda (i.e. "good" projects get funded and get samples), do they enhance quality *because* of the *control on research agenda* they devolve to lay citizens or for other reasons?

The underlying assumption of any mechanism of research agenda setting is that its particular mixture of expert judgment and citizen control ultimately serves the common good. Both private and public boards deciding on funding employ certified scientific experts. These experts speak, as it were, in the name of science. In addition, forms of citizen control ensure that research agendas are responsive to citizens' values and preferences. We have seen that a premise of most existing mechanisms of research agenda setting is that also relatively indirect forms of citizen control are sufficient to ensure such responsiveness. In the case of public institutions, boards deciding on research agendas (e.g. funding) will ultimately respond to elected representatives. Citizen control in this form is of course both indirect and coarse-grained, in the sense that elected representatives will at most influence the very general directions of science policy, while citizen control on representative themselves is only intermittent and partial. In the case of market-based systems of research agenda settings, the assumptions is that companies will eventually respond to market signals: that is, if companies were not to respond to citizens' value and preferences, their business model would not be viable. This is of course an equally limited mechanism for ensuring responsiveness, if only because companies may be able themselves to influence and shape citizens' values and preferences.

The question is whether crowdsourcing can do better than the extant research funding and governance systems because it devolves more power to citizens in the allocation of funding and biological samples. The answer must be qualified. As long as crowdfunding mobilises *additional* resources to resources managed through other channels, it can be seen as a valuable tool to give citizens' voice in research priority setting [Ozdemir, Faris and Srivastava, 2015]. If compared to the total budget allocated to scientific research, however, crowdfunding is still a negligible form of research funding and we can speculate that it may remain inadequate for capital intensive projects. Moreover, it may give disproportionate voice in research agenda setting to those who are educated enough and/or wealthy enough to care about these projects and donate [Schmitt, 2013]. But crowdfunding *does* endow citizens with additional voice in agenda setting: by donating money, citizens could communicate their priorities and their ideas about what lines of research are worth pursuing. Crowdsourcing is an additional channel for ensuring responsiveness and promoting the democratic aspirations of citizen engagement in science. Although crowdsourcing is admittedly a minor determinant of overall research agendas, it should be compared with other existing forms of citizen control on agenda setting, such as markets and elective representatives, which present weaknesses and limitations in their own terms.

Conclusions

Weitkamp [2014] distinguishes "serendipitous" forms of dialogue between scientists and the public from dedicated exercises in citizen engagement such as formal consultations and science shops. We have argued that such serendipitous encounters can potentially be promoted by crowdsourcing initiatives that, despite their being advertised as citizen science, were not designed as spaces for citizen engagement. We have also hypothesised that such encounters are facilitated by the

participatory and democratic language that imbues crowdsourcing. The official ideology of these projects often does not describe what actually happens within the project; however, such ideology may constrain how organisers of CS projects react to "lay" people voice, thereby catalysing citizen engagement. Moreover, crowdsourcing can empower citizens by mobilising financial and biological resources unmediated by traditional funding and research institutions, thereby giving citizens limited but not negligible direct power on agenda setting and promoting the democratic aspirations underpinning citizen engagement initiatives. In summary, crowdsourcing CS projects are implemented to address issues of funding and participants recruitment (i.e. the Schumpeterian rationale), and/or on the basis of organizational theories that gives prominence to horizontal cooperation and open systems. However, they can *catalyse* dialogues between citizens and scientists and empower citizens.

Importantly, scientists and entrepreneurs opting for crowdsourcing will not assess the success of their projects on the basis of the quality of citizen engagement that they are able to promote. CS projects are often designed by actors motivated by very different hopes than to democratise science. Hence we should be cautious when assessing the participatory rhetoric of CS promoters, and devise ways to identify cases where the instrumental employment of participatory language could have harmful effects. At the same time we should avoid dismissing minimalistic forms of participation in science as detracting from the ideal of making science more democratic. In some cases, even purely instrumental forms of crowdsourcing ally with democratic ideals and thus represent a small step in the right direction.

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