Citizen Science and Scientific Objectivity: Mapping Out Epistemic Risks and Benefits

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Given the importance of the issue of scientific objectivity in our democratic societies and the significant development of citizen science, it is crucial to investigate how citizen science may either undermine or foster scientific objectivity. This paper identifies a variety of epistemic risks and benefits that participation of lay citizens in scientific inquiries may bring. It also discusses concrete actions and pending issues that should be addressed in order to foster objectivity in citizen science programs.

1. Introduction

Nowadays, the issue of the nature and sources of scientific objectivity largely exceeds the academic sphere. Indeed, objectivity is commonly considered to be the very basis of the authority of science in our society and is seen as a key precondition for public trust in science. As numerous political decisions call on scientific expertise, questions concerning the very nature and limits of scientific objectivity are becoming central to public debate. At the same time, calls for a larger implication of lay citizens in the process of knowledge and expertise production itself are on the rise. The general concept of "citizen science" refers in the current literature to a large diversity of forms of participation of citizens who are not professional scientists (individual citizens, NGOs, groups of patients, etc.) in the production of scientific knowledge, in ways that go beyond the traditional roles that research subjects have had in the biomedical sciences

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(e.g., in clinical trials) and in the social sciences (e.g., via interviews or questionnaires) (Cooper and Lewenstein 2016; Eitzel et al. 2017).[1] Inclusiveness in scientific research is more and more valued by scientific institutions, as shown by their growing financial support of citizen science and the numerous commissioned reports (e.g., European Commission, 2013, 2016; Office of Science and Technology Policy 2019).

These reports emphasize that the development of citizen science should not be seen as hype, as it corresponds to profound epistemological and political trends affecting the way knowledge is produced in our democracies. On the epistemological side, one of the major evolutions is the massive collection of data, playing a key role in the development of many disciplines - from environmental sciences to astronomy or bio-medicine (Leonelli 2014). And when more and more data are on the scientific agenda, non-academic data collectors are seen, not surprisingly, as a welcomed additional resource for scientific inquiry. On the political side, a larger involvement of citizens in the orientation of research and/or in the production of knowledge is also valued, for the sake of democracy, both in the philosophical literature (e.g., Kitcher 2011) and in global scientific policy strategies: for instance, the notion of "Responsible Research and Innovation" developed by the European commission implies that "societal actors (researchers, citizens, policy makers [...]) work together during the whole research and innovation process."[2] The growing importance of citizen science in scientific practices and in academic and political discourse shows that science is no exception to the broader "participation imperative" that is arising in our democracies (Godden 2017).

On the face of it, opening scientific inquiry to non-professionals may appear quite challenging from an epistemological point of view, to the extent that such opening may impact the internal self-regulatory mechanisms of scientific communities that are commonly regarded as sources of objectivity (e.g., the Mertonian norm of organized skepticism grounded on shared intellectual attitude among professional scientists). Not surprisingly then—recall that "among peers" is the rule in contemporary research—participatory practices sometimes meet resistance from scientists themselves (Riesch and Potter 2014; Golumbic et al. 2017). Indeed, important epistemological concerns have been raised, such those relating to the quality of the data collected by crowd-sourcing programs (Resnik et al. 2015), but also those connected to the lack of neutrality of the militant groups (for instance, NGOs) who engage

1. See Bedessem (2020) for a more systematic analysis of the various meanings of "citizen science" as well as a state-of-the-art of the current literature on citizen science. In this paper, we use the term "citizen" to refer to a *non-professional* inquirer.

2. https://ec.europa.eu/programmes/horizon2020/en/h2020-section/responsible-research-innovation

in citizen science (Sarewitz 2000; Kinchy and Kleinman 2003). But, on the other hand, influential works on scientific objectivity in contemporary philosophy of science value the existence of a diversity of perspectives on a given issue as a condition for well-founded objectivity (Harding 2015; Wylie 2015; Longino 1990), thus departing from the idea of scientific objectivity as a "view from nowhere." These pluralist approaches to scientific objectivity are thus more hospitable (at least *prima facie*) to the opening of scientific inquiries to a variety of actors.

Given the importance of the issue of scientific objectivity in our democratic societies and the significant development of citizen science, it is then crucial to investigate how citizen science may either undermine or foster scientific objectivity and whether current resistance to more inclusiveness is well-founded. To be successful and useful, especially to people engaged in participatory research programs, such an investigation must take into account both the diversity of participatory practices in science and the multiple dimensions of the very notion of objectivity (Reiss and Sprenger 2017; Megill 1994). Consequently, the first aim of this paper is to develop a conceptual framework that allows us to investigate the variety of epistemological challenges posed to scientific objectivity by different forms of citizen participation, as well as the variety of epistemological benefits that participation may bring.[3] The second aim of this paper is, in light of the previous analysis, to identify and discuss concrete actions to be undertaken and pending issues that need to be addressed when designing participatory research programs with a concern for fostering objectivity in mind. We will proceed as follows: building on previous works by various authors, we will first establish a typology of participatory practices in contemporary science that are well adapted to our purpose, as well as a typology of the different meanings of scientific objectivity based on an epistemic risk account of the notion (Koskinen forthcoming; Biddle 2016). By coupling these two typologies, we will establish a cartography of various specific challenges and benefits to objectivity in participatory research programs. In other words, the intersection of the two typologies (objectivity-participation) will lead to distinct objectivity/participation couples (o, p couples) raising specific issues, and we will discuss in each successive case how the kind of participation p may challenge or foster the dimension o of objectivity. For each couple (o, p), we will also discuss concrete actions and pending issues that should be addressed in order to foster objectivity.

3. A more complete approach would have to address ethics challenges in addition to epistemological ones. Indeed, citizen science raises important specific ethics issues (Resnik, Elliott, and Miller 2015; Rasmussen and Cooper 2019) that may eventually bear on the overall epistemic quality of the inquiry. We thank one of our reviewers for mentioning this line of development and leave it to another paper.

2. The Many Faces of Citizen Science

Participation of citizens to scientific inquiries today takes various forms, and several classifications have been proposed in the last decade or so based on social, institutional, or epistemic properties (Bucchi and Neresini 2008; Bonney et al. 2009; Roy et al. 2012; Haklay et al. 2013; King 2016; see Schrögel and Kolleck (2019) for a review of the typologies currently available). In this paper, we adopt the classification proposed by Bonney et al. (2009). The justification of this choice is twofold. First, this classification (or similar ones) is commonly used in the academic and institutional literature on citizen science. Second, its categories reflect different degrees of implication of non-professionals, corresponding to various stages of scientific inquiry, thereby allowing the identification and differentiation of a variety of epistemological challenges. The classification distinguishes three main categories: "contributory" citizen science, "collaborative" citizen science, and "co-created" citizen science.

When engaged in *contributory* citizen science, citizens are passive or active data-collectors supervised by scientists. Numerous examples of this type of citizen science program, also often called "crowd-sourcing" programs, can be found in environmental science. Many countries have for instance developed participative observatories to follow the evolution of biodiversity.[4] The "Zooniverse" platform[5] brings together several research programs, enabling people to participate in research in various fields, from astronomy (classifying distant galaxies) to humanities (transcribing handwritten documents by Shakespeare's contemporaries).

When engaged in *collaborative* science, citizen participation goes beyond the mere collection of data in two ways that are often intertwined in practice. First, under the supervision of professional scientists, citizen may be involved in more complex technical and cognitive tasks, such as the design of methods, of research plans, and the interpretation of results. Second, they may also bring their own specific expertise to the solution of a problem. The "fold-it" program in fundamental biology, for instance, aims at studying the tridimensional structure of proteins by engaging volunteer citizens in a numerical serious game (Kelly and Maddalena 2015). Various other programs exist which demand strong commitment from a specific group of people, identified by scientists as sharing some expertise or skills in a given matter. This is notably the case in agronomic programs for developing countries. For instance, in the project for participatory plant breeding run by the French center for research in agriculture and development (CIRAD),[6] farmers from developing countries

4. See for instance "Vigie-Nature" in France (Couvet and Prévot 2015). For a review on this subject at the international scale, see Palacin-Silva et al. (2016).

5. https://www.zooniverse.org/

6. http://participatory-plant-breeding.cirad.fr/

participate actively in research programs on plant genetic resources, drawing on their own agricultural practices to elaborate knowledge in collaboration with scientists. The World Bank also proposes various similar programs aiming at improving the productivity of agriculture in southern countries, by developing mutual epistemic relationships between citizens and scientists.[7]

In these first two categories of citizen science, the initial formulation of the research problems or questions is mainly made by scientists. In contrast, when engaged in *co-created* citizen science (often also called "community-based research"), citizens initiate a research program aiming at solving a problem that they themselves have identified. In this case, the participants are better described as stakeholders. The notion of stakeholders should be understood here in the traditional sense it takes in the literature on public deliberation (Kahane and Lopston 2013)—that is, as a group of people having a non-cognitive interest in the problem under consideration because they are directly affected by the problem or would be directly affected by its resolution. In these cases, a group of citizens sharing a common concern is heavily involved in all phases of scientific inquiry, from the co-construction of the research questions to the collection of data, the establishment of interpretations, and the diffusion of results. This type of citizen science often takes place in anthropology (Rappaport 2008) and in the fields of public health and environmental sciences (Irwin 1995; Den Broeder et al. 2016; Mielke et al. 2017), where it typically involves a group of people facing an environmental risk (for instance pollution) or affected by a specific disease (for instance, a rare genetic disease).

3. The Many Faces of Scientific Objectivity

Objectivity is notoriously a multi-faceted and historically situated epistemological concept (Daston and Galison 2007). What is required for our project in this paper are what Koskinen (forthcoming) has recently called "usable" notions of objectivity, that is, notions that can *actually be used* to evaluate research activities. And since citizen participation can concern various stages of a scientific inquiry and comes in various shades of involvement, as briefly described in the previous section, we need notions of objectivity that allow us to assess this variety of dimensions. The epistemic risk account of objectivity developed by Koskinen (forthcoming) is particularly well-suited to our purpose. In this perspective, objectivity is linked to the avoidance of an epistemic risk, as defined by Biddle and Kukla (2017, p. 218)—that is, a "risk of epistemic error that arises anywhere during knowledge practices." We say that X (a researcher, a community, a research process, a knowledge claim) is

7. See the World Bank report dedicated to this issue: http://documents.worldbank.org/curated/en/578241468765924957/pdf/multi0page.pdf

objective when we believe that "important epistemic risks arising from our imperfections as epistemic agents have been effectively averted" (Koskinen forthcoming, p. 9). In other words, to a given domain of epistemic risks corresponds a domain of objectivity, in the sense that avoiding this kind of epistemic risks favor objectivity in the corresponding sense. Following Koskinen's approach, we investigate what kind of epistemic risks should be envisaged in the case of citizen science programs. In light of the various kinds of citizen involvement described earlier, we identify three main domains of epistemic risks, hence three kinds of objectivity.

The first domain concerns the reliability and epistemic quality of the experimental and cognitive techniques and processes deployed in a scientific inquiry. In this paper, we shall call the (traditional) kind of objectivity at stake in this domain "Baconian objectivity."[8] The second domain of epistemic risks focuses on issues of impartiality (Lacey 1999). Objectivity then refers to the absence of distortion by explicit non-cognitive interests: it requires that, as epistemic agents, we do not ignore or distort empirical evidence for the sake of explicit contextual (i.e., political, cultural, social, or economic) preferences. The third domain of epistemic risks relevant to citizen science concerns the quality of the interactions between epistemic agents. Following Douglas' (2004) and Koskinen's (forthcoming) terminology, we shall call the kind of objectivity at stake here "interactive objectivity." "Interactive objectivity" requires that transparent processes of critical discussion between agents be ensured. This third kind of objectivity can, to a certain extent, be considered as instrumental to the two aforementioned kinds of objectivity. Indeed, critical discussions between agents involved in a scientific inquiry may for instance allow the revelation and solution of faults in an experimental protocol or the correction of improper use of statistical tools. It may also permit identification of situations in which individual preferences or interests over-ride empirical evidence. But interactive objectivity also points to additional specific benefits for critical discussion, linked to the avoidance of biases by non-explicit, hidden background assumptions (Longino 1990), as we will discuss in greater details below. This third domain of objectivity is thus clearly distinct from the second one, which relates to the existence of explicit biases, whereas the third domain relates to hidden, unexplicit ones.[9] With this tripartite approach to scientific objectivity, our ambition is not to cover exhaustively all kinds of epistemic risks, but to distinguish between three domains of epistemic risks that are

8. This simply refers to Bacon's caveat in *The New Organon* (Book I, aphorism 4) against "discoloring the light of nature" in the course of a scientific inquiry.

9. Note also that Harding's notion of strong objectivity (2015) is relevant here to the extent that the existence of such background assumptions is related to the social, cultural, and political location of the epistemic agents.

relevant for citizen science and that each raise specific issues, both theoretical and practical.

4. Mapping Out Epistemic Risks

By crossing our three-dimensional typology of objectivity (Baconian, value-impartial, and interactive) and our three-dimensional classification of citizen participation in science (contributory, collaborative, and co-created) we identify and discuss in this section, for each couple (*o*, *p*), epistemic risks and potential benefits of participation, as well as theoretical and practical obstacles or challenges still to be overcome in order to foster better citizen science practices. Results of this analysis are summarized in Table 1. We start with Baconian objectivity and investigate successively how each type of citizen science may impact it.

4.1. Baconian Objectivity

As Baconian objectivity is dependent on the reliability of the protocols (observational, experimental, inferential, etc.) followed by the inquirers, epistemic risks and potential benefits of citizen participation will vary with the phase of the scientific inquiry and the difficulty of the associated tasks. Let us turn first to citizen participation restricted to the phase of data collection, that is, contributory citizen science.

Table 1. Q1

Citizen science / Objectivity	Contributory (Citizens as data collectors)	Collaborative (Citizens participate in virtue of their expertise)	Co-created (Citizens co-construct the problems to be solved)
Baconian (reliability of the experimental or cognitive techniques used)	*Benefits (+)/ Risks (-)* • More data(+) • Issues of reliability of the data collection protocols (-) --- *Challenges/pending issues* • Efficient techniques and spaces of interaction with non-professionals • Expend interactional skills of professional scientists	*Benefits (+)/ Risks (-)* • Contribution of lay expertise (+) • Issues of reliability of inquiry. protocols (-) --- *Challenges/pending issues* • Issues of integrability of different systems of knowledge • Balanced interactions between non-professional and professional inquirers	*Benefits (+)/ Risks (-)* • Enrichment of the pool of research questions (+) • Incentives to strengthen the reliability the protocols of inquiry (+)
Impartiality (no distortion by explicit non-cognitive interests)	*Benefits (+)/ Risks (-)* • Better control of conflicts of interests (+) • Issues of scientific integrity (-) --- *Challenges/pending issues* • Implementation of science integrity regulations adapted to citizen science		*Benefits (+)/ Risks (-)* •Unbalanced production of scientific expertise (-) • Fragmentation of the research agenda (-)
Interactive (transparent process of critical discussion between epistemic agents is ensured)	*Benefits (+)/ Risks (-)* • Interactive learning processes between citizens leading to expert-citizens (+)	*Benefits (+)/ Risks (-)* • Increased efficiency of transformative criticism processes (+) • Asymmetry in responses to mutual criticism (-) • Lack of shared practices and norms of interactions, lack of mutual trust and understanding (-)	

4.1.1. Contributory Science. When a research program mobilizes non-professionals as data collectors, a first, straightforward potential epistemic benefit is simply: more data. But its value evidently depends on the quality of the data collected. The ability of the data collectors to appropriately follow protocols and rules designed by professional scientists is thus the key source of epistemic risks. At least three responses to this issue of data quality have not only been discussed in the literature on citizen science but also implemented in citizen science programs: training of the participants, interactive adaptation of the protocols, and *ex-post* control of data quality. Let us briefly discuss them in turn.

As noted by Kosmala et al. (2016), training is the most obvious approach to improving data quality, and most existing citizen science programs include a phase of training. It has been shown in different projects in ecology and environmental sciences that effective training allows participants to produce data of a quality similar to the quality of data produced by professional scientists (Prysby and Oberhauser 2004; Danielsen et al. 2014). In some programs, this training is associated with a measurement of the reliability of the participants, by using skill tests. The result is then used by professional scientists to select participants (see for instance Watson and Floridi (2016) on how this is achieved by the Zooniverse numerical platform, the world largest citizen science portal).

Concerning the production of adapted protocols by scientists, a first (obvious) challenge is to design easily understandable protocols to be used by lay citizens. Beyond this *ex-ante* production of accessible scientific guidelines, interactive processes between citizens and scientists are also implemented to adapt protocols in the course of the scientific inquiry. Some programs have implemented such an iterative improvement of the tasks performed by volunteers, by designing, testing and comparing various simple and reliable data collection protocols (Crall et al. 2010).

Ex-post control of data quality is by no means reserved to citizen science programs, but it does take specific forms in this kind of scientific inquiry. As noted by Haywood (2014), there already exists a large variety of techniques used by scientists to manage and control the reliability of large data sets collected by non-professionals. For instance, Watson and Floridi (2016) describe how various biases are corrected in the Galaxy Zoo project: classification is weighted by considering the tendency of each user to divert from the majority. In ecology and environmental sciences, Kosmala et al. (2016) explain how systematic errors are modeled and corrected: these corrections can concern biases also well-known in professional communities such as classification biases, or more specific ones, such as the high variability among volunteers in terms ofability, effort, or commitment. In this latter case, statistical methods have been developed to attenuate the effects of such variability. In other cases, automatic filters are used in order to verify *ex-post* the internal consistency of the data sets collected by each participant (Kelling et al. 2011). In ecology and environmental sciences, citizens may be asked to regularly deliver some samples (for instance, a photo, a video, or a physical specimen) justifying the identification and classification they make (Delaney et al. 2008). These samples are then used by professional scientists to measure the accuracy of the data collected and classified by the participants.

When proper training and interactive processes of adaptation of protocols are implemented, the current literature on data quality in citizen science programs suggests that scientists manage to successfully control the epistemic risks raised by entrusting the task of data collection to non-professional collectors (Chatzigeorgiou et al. 2016; Kosmala et al. 2016). As regards Baconian objectivity, the main challenge for professional scientists in contributory citizen science programs thus turns out to concern the creation of efficient techniques and spaces of interaction with non-professional scientists. It should be noted that this kind of communication and organizational skills are not part of the set of technical and social skills usually expected from a good scientist, since professional scientists are primarily trained to interact with each other, rather than with non-professionals. Therefore, the main challenge here is not so much epistemological than educational and social: expected skills for professional scientists (or at least for a subset of professional scientists) should also include the ability to interact efficiently with non-professionals (who are not in the usual student-mentor relationship).

4.1.2. Collaborative Science. In collaborative science, we have seen that citizens may make two kinds of contributions, often intertwined in practice. Under the supervision of professional scientists, citizens may be involved in more complex technical and cognitive tasks than data collection, such as the design of methods, of research plans, and the interpretation of results, and they may also bring their own specific expertise to contribute to the solution of a problem under the supervision of scientists. As regards the first form of contribution, here again, as in contributory science, the main challenge to meet is in terms of control by professional scientists of the technical and epistemic quality of the various tasks performed by the lay participants. Ex-post control procedures and interactive training are also the main tools usually employed to control this kind of epistemic risk associated with Baconian objectivity. Bonney et al. (2009) provides various examples of such strategies. Consider for instance the "salal harvest sustainability study" (2001–2004) that aimed at determining the effect of harvest intensity on the plant's growth (Bonney et al. 2009 p. 32). This project enlisted the salal harvesters to select the sites where the data would be collected, to design the methods and standards to measure the effects of harvesting, and to collaborate on the interpretation of data. To ensure that this collaboration led to reliable knowledge, professional scientists and harvesters interacted before, during, and after the program. The harvesters first followed training on the basic elements to be taken into consideration when selecting sites, designing a method of measure, and interpreting the results. The analysis of the results was made in the context of a collaborative workshop where citizens interacted with scientists to discuss the graphs obtained, and the recommendations for the future. After the program, the impact of the project in terms of education and knowledge gain for the harvesters was assessed through an interview by an exterior evaluator, in order to evaluate the efficiency of the technical and cognitive learning attained by the participants. Overall, the current literature assessing the quality of the knowledge produced by this kind of collaboration suggests, as for contributory science, that the epistemic risks associated with Baconian objectivity may be successfully averted, provided that adequate spaces and techniques of communication and collaboration are set up (Parrish et al. 2018; Herman-Mercer et al. 2018)

As mentioned above, collaborative science is not only a matter of benefitting from a larger task force, so to speak, in every phase of a scientific inquiry, but is also a matter of drawing on the lay expertise that the participants may bring.[10] What then are the specific challenges and benefits of this kind of citizen contribution? First, concerning the potential benefits, a growing literature points to various robust epistemic gains, such as enriching the pool of data available to scientists or enlarging the space of possible causes to be considered in the interpretation of a given phenomenon. In the biomedical field, for instance, a well-documented case is the contribution of AIDS patients, who brought their proper expertise on side-effects of their treatment to help develop better understanding and treatment of the disease (Epstein 1995; Godlee 2016). Another well-known example of the successful contribution of lay expertise is provided by Wynne (1998), with his now classical analysis of the "Cumbria sheep": the specific expertise of the shepherds on sheep grazing turned out to be essential to scientists to understanding the effect of radioactivity on the natural environment of this region of England. In archeology, Wylie (2015) discusses how collaborative practices between professional archeologists and descent communities (e.g., indigenous people) may favor, and have actually significantly improved archaeological science. Beyond their specificities, such cases have in common the fact of showing that the participation of citizens who contribute their own lay expertise can increase Baconian objectivity, to the extent that it can improve the overall epistemic quality of the scientific inquiry process in various ways: it can enrich the pool of available data by making visible to professional scientists phenomena or data that were invisible to them, and it can

10. The notion of lay expertise is often used in the literature to refer to various forms of expertise developed by people who are not professional scientists. A lay person may acquire some scientific knowledge and methods to be able to interact with professional scientists and experts. She may also draw on her own life experience or professional experience to acquire her own specific expertise. It is sometimes the case that lay expertise mixes both.

improve the interpretation of data and the understanding of a phenomenon by providing interpretative perspectives inaccessible to professional scientists.[11]

Beyond the analysis of cases of successful contributions of lay expertise, it would be interesting, on a more general note, to investigate the conditions fostering the successful integration of lay expertise into a scientific inquiry. From an epistemological point of view, this would take us to issues of the integrability of different types of knowledge, to the extent that lay expertise refers to some type of knowledge grounded in one's specific experience. The recent philosophical literature on scientific pluralism could be a resource here, even if it has so far mainly focused on issues of the compatibility (or incompatibility) of different models, approaches, and theoretical perspectives produced *within* science, typically in different disciplines (e.g., Longino 2013; Mitchell 2003; Ruphy 2016).[12] From a more practical perspective, it should first be noted that cases of successful contribution of lay expertise such as those mentioned above are not without difficulties concerning the interaction between professional scientists and lay citizens (Kullenberg 2015). This should not come as a surprise. After all, as often emphasized in the literature on interdisciplinarity, it is hard enough to get professional researchers from different disciplinary backgrounds to interact and work smoothly together. Issues of a lack of mutual understanding, the lack of a common language, "imperialism" of one discipline over another etc., often hamper the inquiry (Mäki et al. 2018). The challenge is obviously even greater when it comes to collaborative science involving professional scientists and lay experts coming from very different epistemic (and sometimes cultural) backgrounds. Here again, as in the case of contributory science, we suggest that the training of professional scientists (or a subset of them) should be reconsidered, so that it also includes epistemological elements on lay expertise as well as practical training on how to deal with non-professional experts.

4.1.3. Co-Created Science. When engaged in co-created science, citizens (as stakeholders) collaborate with scientists to resolve specific problems that they themselves have identified and are thus more autonomous in the inquiry process when compared to the two previous types of citizen science. A straightforward benefit of co-created citizen science is an enrichment of the pool of

11. Standpoint theories provide here a very useful theoretical background to aid in grasping this kind of epistemic benefit (see for instance Rolin (2016) for a recent overview of standpoint theories), especially Harding's notion of strong objectivity (2015). See also the notion of "local epistemology" (Longino and Lennon 1997). In the sociological literature, Collins and Evans (2002) offers a now classical discussion of the epistemic contribution of lay expertise.

12. Koskinen and Mäki (2016) is a programmatic paper pleading for more involvement of pluralist philosophers in the study of extra-academic transdisciplinarity.

questions addressed by scientific inquiry, resulting in an enrichment of the pool of available data, to the extent that some data are collected directly in relation to the new questions brought to light by citizens. But we would contend that the most significant link with Baconian objectivity results from a kind of second order mechanism. In the case of co-created science where citizens are more autonomous, professional scientists are not in a position to closely manage and control every step of the inquiry in order to increase its reliability and epistemic quality. However, there exists a strong incentive for the stakeholders collaborating with professional scientists to ensure Baconian objectivity. Since it is (still) widely considered as the basis of epistemic authority, Baconian objectivity is valued and sought after by the stakeholders in order to get recognition by political and scientific authorities of the reality of the problems they are facing. In other words, it is in their interest, when collaborating with professional scientists, to conform to the usual standards of reliability and epistemic quality in place in scientific communities if the stakeholders want their practical problems to be taken into serious consideration. Let us illustrate this point with a well-known example of a co-created research program in the environmental sciences. As they were living near a Shell plant, a group of inhabitants of the Diamond subdivision in Norco (Louisiana) decided to assess the air pollution that they were undergoing.[13] The citizens collected the air samples using "buckets" and the analysis of the samples was performed in professional laboratories. Their goal was to convince professional scientists of the reality of the risks to their health posed by the Shell plant. They thus had a strong incentive to strengthen the reliability and epistemic quality of the data they were collecting, by conforming to usual scientific protocols and standards of data collection. Citizens also interpreted and discussed the results of the analysis of samples, in light of the standards officially used by authorities concerning acceptable levels of concentration. In addition, they discussed the overall reliability of the methods (e.g., distribution of the measurements points, frequency of the measurements) and standards used to assess the environmental contamination due to the Shell plant, showing that some revisions were required in order to improve the epistemic quality of the risk assessment (Ottinger 2010).

4.2. Objectivity as Impartiality

Epistemic risks in the domain of impartiality are mainly linked (not surprisingly) to issues of conflicts of interests and, more generally, to research misconduct, but also, in the specific case of co-created science, to issues of unbalanced production of expertise and fragmentation of the research agenda.

13. We draw here on the detailed presentation of this case given by Schrögel and Kolleck 2019.

4.2.1. Contributory and Collaborative Science. When citizens involved in various stages of a scientific inquiry have stakes in its outputs, a first (obvious) risk is that in order to reach a particular outcome, they may be tempted to depart from standards of integrity in research. For instance, having stakes can incite the modification, fabrication, or falsification of data, thus undermining the overall reliability and epistemic quality of the inquiry. But is the risk serious? To the best of our knowledge, there are no studies evaluating this effect. As in the case of scientific misconduct (including conflicts of interests by professional scientists), such misconduct is difficult to document. An interesting - and still pending – issue is whether the control mechanisms, regulations, and institutional measures that are increasingly implemented in scientific communities to foster research integrity could be successfully applied to a larger community that includes non-professional inquirers. We suggest that it is unlikely, if only because the reputational mechanisms and scientific reward systems that play a central role in the auto-regulation of scientific communities are not present in larger, non-professional communities. However, as for professional scientists, a minimal safeguard that could be implemented in citizen science programs is asking participants to report on possible conflicts of interest, in order to foster transparency.

Interestingly, involving citizens having stakes in the outputs of a scientific inquiry can also bring benefits as regards objectivity as impartiality. As stakeholders, participants may pay more attention to the existence of potential conflicts of interest in professional researchers. Yamamoto (2012) gives the example, in environmental sciences, of militant groups having developed an expertise on the credibility of professional scientists, by systematically controlling biases due to potential conflicts of interest. Mutual checking by professional and non-professional inquirers on possible conflicts of interests may thus foster value impartiality objectivity (Elliott et al. 2017).

4.2.2. Co-Created Science. In addition to the previously-mentioned risks that it shares with contributory and collaborative science, co-created science is subject to a specific epistemic risk related to issues of unbalanced processes of acquisition of scientific expertise on a given phenomenon or problem to be solved. This is especially the case with multifaceted environmental or public health issues. In such cases, various stakeholders with divergent political or economic interests engage in co-created science programs in order to produce scientific expertise concerning a limited dimension of the general issue, in relation to their interests. Some authors have emphasized that this multiplication of interest-related assessments often turns out to be detrimental both epistemologically and politically (Sarewitz 2000, 2004; van der Vegt 2018). On the epistemological side, some aspects of a phenomenon may be understudied because it is unlikely to serve the interests of a dominant group. For example, to put it (too) briefly, anti-GMOs will favor the production of expertise on potential negative impacts on the environment, whereas the food industry will favor studies on yield increase.[14] Consequently, the overall production of scientific expertise may be unbalanced: some aspects will be thoroughly studied whereas others will be understudied, depending on power relations. In other words, however unbiased and correct each individual assessment may be, the overall picture resulting from their juxtaposition can be biased, to the extent that it overemphasizes some aspects in regard to other, understudied aspects. This kind of epistemic risk has political consequences. In public debates, selective appraisals often appear as conflicting appraisals (even when they do not address the same aspect of the multifaceted issue at stake) because they are put forward in support of different, conflicting political actions. And this, in turn, complexifies and slows down processes of consensus formation, and hence political action.

Another risk worthy of being discussed here is the risk of fragmentation of the research agenda. Since co-created science programs are mainly developed by local communities to respond to specific interests or to solve specific problems that they face, the multiplication of such programs may lead to a juxtaposition of research questions selected mainly on the basis of the political visibility or activism of the stakeholder groups concerned. While how best to ensure that every community is given a fair chance to develop the research program it needs is a politically crucial issue, it is not the one that we will address here. We will rather focus on the epistemological issue raised by the potential effect of the fragmentation of research questions. Let us first rephrase this using the notion of "exogeneous" problem, as defined in Bedessem and Ruphy (2019). An exogeneous problem or research question is simply a problem identified and formulated outside (or at least partly outside) a scientific field, incorporating various interests and expectations (not only those of scientific communities), by contrast with an "endogenous" problem. Research questions addressed in co-created science programs are typically exogeneous. To what extent, then, may the juxtaposition of exogeneous problems be problematic from an epistemological point of view? Our answer to this question will be given in two stages. First, we will recall a general point made in Bedessem and Ruphy (2019) about the epistemic fecundity of integrating exogenous questions into the research agenda. Second, we will discuss whether such epistemic benefits may be gained in the specific case of exogenous problems addressed in co-created science programs.

Drawing on various cases studies, especially in the field of biomedicine, Bedessem and Ruphy (2019) shows that the integration of exogeneous problems in the development of a research program may lead to the

14. See Biddle (2018) for a much more detailed analysis of this controversy over GMOs in terms of differences in values and interests, also Hicks (2015).

opening of new and fecund directions of endogenous inquiry. In other words, the co-orientation of a research program by the integration of exogeneous problems within endogenous ones may be epistemologically virtuous to the extent that it leads, in addition to the resolution of practical problems, to an enrichment of the fundamental knowledge and the set of endogenous research questions in the domain concerned.[15] Let us turn now to the case of exogeneous problems added to the scientific agenda by co-created science programs. Can one expect the same kind of epistemic benefits? By contrast with the aforementioned "traditional" (i.e., non-participatory) research programs, we lack historical and epistemological studies on the impact of such exogeneous problems on the development of a given field of academic research. But our hunch is that their impact may not be particularly significant for the following reason: in the case of co-created science programs, exogenous problems added to the scientific agenda often require a local solution, which may not require the opening of any new lines of inquiry likely to increase fundamental knowledge in the domain concerned. In other words, in the case of co-created science, the selection of exogeneous problems is generally not made in light of their potential interest for the development of the field as perceived by professional scientists but, rather, in light of their urgency, from a practical point of view, of finding a solution. Consequently, the epistemologically virtuous effect of integrating exogenous to endogenous problems seems less likely to occur. One might rather end up with a multiplicity of specific exogeneous problems needing to be solved in isolation, without integration in a common research agenda. This fragmentation of the research agenda may not be deemed at all problematic from a practical (and political) point of view, when what matters most is to be able to solve local problems. But from an epistemological point of view, there is a risk is of weakening the virtuous dynamics of integrating exogeneous problems within endogenous ones.

4.3. Interactive Objectivity

Since interactive objectivity requires the implementation of transparent processes of critical discussion between agents, epistemic risks in the domain of such objectivity will generally turn out to be linked to issues of shared standards and culture.

4.3.1. Contributory Science. When citizens are involved as collectors of data, transparent processes of mutual criticism take the form of mechanisms of mutual control and interactive learning between citizens, with the more

15. As discussed in more detail in Bedessem and Ruphy (2019), a good example of this epistemologically virtuous integration is given by the history of molecular biology. The practical search for new cancer treatments by targeting molecular regulation networks ("rational drug design") has strongly fostered the acquisition of new fundamental knowledge in cell biology (Adam 2005).

experienced guiding the less experienced, as described for instance by Cosquer et al. (2012) in the case of contributory science programs developed in biodiversity and conservation sciences. On a more general note, we suggest that a better understanding of these interactive learning processes and of the organizational conditions of their success is thus an important element for fostering interactive objectivity.[16]

4.3.2. Collaborative Science and Co-Created Science. Well-known insights from social epistemology suggest that proper processes of critical discussion between epistemic agents allow the influence of hidden background assumptions to be made apparent at various stages of the scientific inquiry, thereby limiting biases and increasing interactive objectivity. Such processes of "transformative criticism" (Longino 1990) are all the more efficient when the heterogeneity of perspectives of the agents involved is high: the less shared background assumptions there are, the more likely the role they play will become visible and can thus be challenged. As initially discussed by Longino, interactive objectivity is enacted by transformative criticism taking place within scientific communities. And in order to achieve "the transformative dimension of critical discourse", scientific communities must satisfy four criteria that are worth being recalled here: "(1) there must be recognized avenues for the criticism of evidence, of methods, and of assumptions and reasoning; (2) there must exist shared standards that critics can invoke; (3) the community as a whole must be responsive to such criticism; (4) intellectual authority must be shared equally among qualified practitioners" (Longino 1990, p. 76).

When it comes to assessing the potential epistemic benefits and risks of involving citizens in more complex technical and cognitive tasks than the simple collection of data, the main question that needs to be addressed is as follows: to what extent, and under what conditions, can these insights from social epistemology be extended beyond the frontiers of scientific communities?

On the face of it, the inclusion of non-professional inquirers in processes of transformative criticism appears beneficial since it is very likely to increase a heterogeneity of perspectives, and thus the efficiency of the critical process.[17] But this holds only when the four above-mentioned criteria are satisfied. Is it likely to be the case with collaborative and co-created science? Let us here make clear the potential difficulties for a more inclusive process of transformative criticism. As Longino explains when discussing the criterion of shared standards: "in order for criticism to be relevant to a position it must appeal to something accepted by those who hold the position criticized" (1990, p. 77).

16. See Jennett et al. (2016) for an example of such studies in the case of online citizen science programs.

17. See for instance Wylie (2015) for an epistemically successful example in archeology.

In other words, agents involved in transformative criticism must feel bound by the standards. Admittedly, it is not necessary that the different subcommunities share all the standards, but there must be some overlapping subsets of standards that are shared by all. Shared professional training ensures that this becomes the case for subcommunities within scientific communities (e.g., empirical adequacy, at least, is expected to be a shared standard). In principle, a first difficulty for the extension of transformative criticism beyond scientific communities is thus a possible asymmetry in responses to mutual criticism: some subcommunities may not accept criticism because they disagree on central norms of justification (for instance a subcommunity may not feel bound by the standard of empirical adequacy when it runs counter to authority or tradition). On a more practical side, another difficulty can arise from a lack of shared practices and norms of interaction and communication. Here again, within scientific communities, common professional training ensures that scientists share tacit knowledge concerning how to communicate with each other and when, for instance, another member of the group can be trusted or not. When scientists come from different disciplines, the price of communication and of a lack of mutual understanding rises quickly, as abundantly noted in the literature on interdisciplinarity (e.g., MacLeod 2018). On the face of it, difficulties can only be all the more serious in the case of extra-academic interdisciplinarity (here co-created research). And indeed, as Steel (2019) reminds us when discussing the epistemic effects of diversity in relation to the elaboration of information, the effect of diversity represents a "double-edged sword," whose negative edge is the following: "demographic diversity may generate obstacles to communication and trust, which may impair group performance" (Steel et al. 2019, p. 2). Such difficulties are no doubt real and serious. And they are also still largely underanalyzed: empirical studies of the effects of demographic and cognitive diversity within scientific communities (not to mention within co-created science) are still very few and far between, and even if the philosophical literature on diversity in science—including citizen science—is growing fast, it is too early to reach any definitive conclusions. The practical and organizational conditions under which the epistemic benefits of transformative criticism within scientific communities can be extended beyond the frontiers of such communities is still very much an open research question, both empirically and theoretically. In particular, empirical studies of actual cases of transformative criticism involving citizens are greatly needed.

5. Discussion

Table 1 sums up the main epistemic benefits, challenges, and pending issues that we have identified with regard to objectivity in citizen science programs. Without attempting to be exhaustive, our aim in this paper has been to provide a cartography bringing to the fore the variety and specificities of the challenges to be met in order to foster objectivity in citizen science, as well as a number of open research questions calling for more empirical and theoretical work. Two main (and related) lessons can be drawn from this cartography. First, from an epistemological point of view, no obstacle has been identified that could not be overcome, at least in principle. Most tools ensuring objectivity within professional scientific communities (e.g., control processes of data quality, transformative criticism) could in principle be extended to more inclusive communities of inquirers. This is not to say that making these tools efficient beyond the frontiers of scientific communities is easy in real life, but we suggest that the difficulties are not different in nature from the difficulties faced within professional research communities engaged in interdisciplinary work. Second, it turns out that the main challenges are thus not so much epistemological as institutional and cultural. As many historical and sociological works have taught us, scientific communities are characterized by a very high level of closure ("among peers" is still the general rule). Communicating and interacting with lay people in the context of a research inquiry and valuing their expertise is not part and parcel of scientific training and culture. Such skills may be acquired on the job, but they are not in general valued for career advancement by most scientific institutions. Thus, and beyond financial support, what is needed from scientific institutions are also new incentives for professional scientists (or a subset of them), especially as regards evaluation criteria and professional training. In other words, what is needed is not only an increase (as is usually claimed) of the scientific literacy of citizens, but also an increase of professional scientists' literacy concerning lay knowledge and expertise.[18]

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18. When lay knowledge refers mainly to scientific knowledge and methods acquired by people who are not professional scientists, literacy on lay knowledge amounts to make professional scientists aware of such epistemic resources, thereby developing their capacity to interact on scientific grounds with non-professionals. When lay knowledge refers mainly to some knowledge grounded on one's own specific life or professional experience, literacy on lay knowledge amounts to inform professional scientists on the relevance of this type of knowledge for scientific inquiry, thereby also developing their capacity to interact with non-professionals and to draw epistemic benefits from it.

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1. Please provide title caption for Table 1.

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