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The many modes of citizen science

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Citizen science is currently heralded by proponents for science and policy in many ways. From a science policy perspective, citizen science is often brought forward as a remedy to 'alternative facts' and to general issues of trust in science and politics. In many cases citizen science has been promoted in sociotechnical imaginaries of creating the 'open society' by democratizing science, facilitating scientific literacy, often via digital technologies and networking (Holocher-Ertl and ZSI, 2013; Nascimento et al., 2014). Here, an imaginary from science policy has emerged, one wherein citizen science is meant to "enable citizens and citizen groups to participate in evidence-based policy and decision-making" (Lamy, 2017:19).

However, in contrast to such general accounts, this special issue seeks to unpack citizen science, and instead approach it not as *one,* but as *several* different modes of social epistemologies. These diverse modes also instantiate a wide range of imagined epistemic agents; 'the citizen', 'the volunteer', 'the participant', 'the crowd', 'the activist', 'the community' et cetera - agents that in one way or another perform scientific research without being a professional scientist. The reasons are as manifold as the identities. Sometimes citizens react to environmental injustice by creating their own instruments and data. Sometimes volunteers join already defined basic science projects and follow their programmatic guidelines, instructions and protocols. The motivations can be quite diverse; from the love of nature and science, to fascination with stellar objects, playing a competitive science game or just passing time.

This special issue of Science and Technology Studies is concerned with the epistemological and ontological diversity of citizen science, and the sometimes contested attempts to define it, as an interesting and fruitful phenomenon to explore from vantage points or perspectives in STS. During the past two decades there has been an increasing interest in this phenomenon, and currently citizen science is being introduced as a way to change the very landscape and culture of science. Citizen science, as constructed as something new and innovative, is however possible to trace in scientific publications back to at least the 1960s, and the notion is sometimes extended onward to the beginning of the 20th century, even if the concept 'citizen science' has its roots in the late 1980s and early 1990s. Historically, however, as Strasser et al. point out in this special issue, it is impossible to conceive of citizen science without the emergence of professional scientists in the mid 19th century. It is actually professional science that is 'the new thing', and the citizen scientists have been there all along in the shadows. The professionalisation of science has in many cases even made volunteer contributors invisible, since scientists have often mistrusted their abilities, and eclipsed them away from proper acknowledgement in publications (see for example Cooper et al., 2014). However, this was also the case in the dawn of modern science, with examples from Robert Boyle and Carl Linneaus relying on a distributed network of helpers that disappeared in history while the image of the great genius scientist was successively constructed and socially as well as ideologically reinforced (see Shapin and Shaffer, 2011).

In STS the notion of citizen science is often associated with Alan Irwin's 1995 book *Citizen Science: A Study of People, Expertise and Sustainable Development*. Here Irwin analyses forms for deliberative governance in terms of the possibilities of a scientific citizenship in which people affected by the consequences of science and technology demand a say in decision-making; from the vantage point of politicians and also scientists such exercises tend to be configured primarily as a practice of public engagement which is concerned with involving the public as stakeholders in policy issues with an eye to establish legitimacy for the science conducted and the science policy decisions made. Well known examples would be deliberations on fishing quotas, nuclear power or gene technology, controversial issues in which the experts and what is often referred to as 'lay people' have had conflicting interests, knowledges and access to information. We might say that Irwin's core problem is the contradiction between epistocracy and democracy, where experts in science and technology often have a privileged position that informs decision-making in a way that short-cuts democracy.

However, this contradiction as described by Irwin, and many other STS scholars, unfolds in quite different directions when citizens not only are affected by scientific expertise, but themselves are creating or co-creating scientific knowledge. This rapidly expanding practice is the focal point of this special issue, in which citizen science is analysed from many angles. In light of these developments, this special issue suggests how STS itself can re-consider what is meant by citizen science. There are at least two broad trends in the relationship between science and citizens that prompts further reflection and empirical case studies:

Firstly, in 1996 Rick Bonney (Bonney, 1996) coined the term 'citizen science' from a very different standpoint than Irwin. Based at the Cornell Lab of Ornithology he described the type of research that had relied on volunteer observations of wildlife, especially birds, for a long time, but had the potential to grow with the emergence of new information- and communication technologies. This type of citizen science is initiated by professional scientists, who define research questions and protocols for classification and collection of data, and then solicit volunteer contributors to assists researchers with predefined tasks, often with the aim of being able to scale up such operations to include thousands of citizen scientists who can help speed up data collection and classification. The idea of the citizen and citizenship is indeed very different in this type of research practice since much of the research process is already staged by experts. However, critical accounts that simply dismiss this practice as 'crowdsourcing' and even as clever ways of recruiting free labour, mostly overlook more nuanced results of empirical studies. For example, Kasperowski and Hillman (2018) have shown that volunteer participants in Galaxy Zoo invent new ways of detecting artefacts in telescope images of galaxies and Ponti et al. (2018) have studied how epistemic cultures and values will develop in quite different ways contingent on whether or not the citizen science projects involve or do not involve gamification. Moreover, several studies have shown that participation in projects on biological conservation is often motivated by concerns of preservation and environmental issues and also involve learning (Jordan et al., 2011, n.d.; Liberatore et al., 2018).

Secondly, and perhaps more intuitively related to scientific citizenship, forms of citizen science exist that grow out of community initiatives in the collection and use of data in legal or political battles, frequently triggered by an environmental risk or health related issues. However, in contrast to Irwin's discussion on science shops and social experiments these community initiatives are created by non-professional scientists that formulate the scope and design of the entire research process in opposition to established scientific knowledge. Examples would include a diverse line of initiatives, from the Louisiana Bucket Brigades (Ottinger, 2010) fighting against the petrochemical industry, German/European Luftdaten.info that measures particulate matter in the air of polluted cities and Safecast, a project for mapping radioactivity downfall after the Fukushima disaster, only to name a few. Such initiatives rely heavily on scientific standards and technologies for validating data as a means of forming resistance against environmental inequalities (Kullenberg, 2015). Since the results of their investigations are often heavily scrutinized and criticized, perhaps in some cases even more so than the peer review practice of institutionalized science, they often employ innovative open science methods and practices. The drivers of this type of citizen science 'in the wild' do not always call themselves advocates of 'citizen science', but prefer terms such as 'civic science'. They wish to highlight that their practices embody an ethos of bottom-up expertise created by concerned people that are not sufficiently represented by current expert systems (see for example Public Lab, https://publiclab.org/about).

The rationale for this special issue is to explore how these forms of practice are transgressed or may even stand in mutual opposition to each other. The five contributions address both what citizen science is, and how it can be studied, as such they are all more or less concerned with attempting to define, delimit or extend the concept of citizen science, even making room for abandoning the concept altogether and replacing it with more contextually aware framings and conceptualizations. No matter where the reader arrives after thinking together with the authors of these articles, we hope that the contributions will spur further discussion and studies within STS communities. With the contemporary wish from science, policy and society for a more open and inclusive science, this will be a key question for scholars in the field.

The first paper in this special issue is by Sascha Dickel, Christoph Schneider, Carolin Thiem and Klara-Aylin Wenten, who focus on civic technoscience and point to the need of distinguishing it in contradistinction to citizen science and clarifying the differences and respective implications involved. While the latter is concerned with explaining the world, the accent in the former is more on constructing viable technological worlds. The different forms or approaches of civic technoscience; emancipatory, entrepreneurial and communicative, are shown to stage the actors in different ways compared to the often-heard rhetorical narratives associated with such initiatives. The authors clarify the processes of inclusion and exclusion in these 'ideal types' as heterogenous publics are assembled as 'performing audiences' in the technological worlds of civic technoscience.

The opportunities for citizen science, particularly the possibilities of community driven citizen science supportive of progress in environmental protection beyond the research phase is the subject of the discussion paper by Shannon Dosemagen and Alison Parker. They illustrate such possibilities along a spectrum of engagements with environmental issues as both US institutions and agencies move toward more inclusive visions of their tasks in tandem with a growth in community science where questions and methods are developed by local concerned groups. They propose a spectrum 'model' of engagement encompassing community initiatives, including education, research, management and regulatory decisions to enforce particular measures; all of this is exemplified by case studies for each category of activities concerned.

In her article on "Modes of Existences in Citizen Science: Thoughts from Earthquake Country" Charlotte Mazel-Cabasse explores the many existences of the risk of earthquakes to inform and complicate the discussion of what citizen science can and cannot be. Discussion pertains to three - of possibly even more - modes of existence of earthquake phenomena: (1) observation, collection of data and translation of mechanisms (of an earthquake), (2) visualization and quantification of the same and (3) personal and affective dimensions of the phenomenon. These modes of existence are all held to incorporate performative capacities. No mode of existence only describes an external reality, but rather in every instance it also works upon, transforms and modifies this reality. Opening up for such ontological issues prompts the question of what citizen science is and could be. A question is: which modes of existence are rendered invisible in the performative acts of inviting the 'outsider' – subjectivity, non-rationality – in the mode of existence that actualises a phenomenon as "scientific"? Mazel-Cabasse shows that subjectivity and non-rationality is never absent in any of the many modes of existence realizing an earthquake. This finding could be extended to the constitutive dimension of all objects of citizen science, for example, galaxies, birds, invasive species, air quality and more. The "quantification by means of instruments" currently appears to be the preferred mode of reducing phenomena to a mode of existence that sits well with citizen science.

The article "'"Citizen Science"? Rethinking Science and Public Participation" by Bruno J. Strasser, Jérôme Baudry, Dana Mahr, Gabriela Sanchez and Elise Tancoigne takes a broad view of what citizen science can be, ranging from epistemology to policy, to its social composition, as well as many different imaginaries of participation and democracy. They suggest that citizen science can be broken down to five distinct 'epistemic practices'. The epistemic practices identified that are able to better capture the diversity of citizen science projects are the following; 'sensing', 'computing', 'analysing', 'self-reporting' and 'making'. Such ideal types of epistemic practice, the authors argue, are more inclusive than simply using the notion of 'citizen science'. This is because they also incorporate other forms of scientific practice that are vital for understanding the many new forms of public participation in the production of scientific knowledge, practices that are easily overlooked when citizen science gains traction and greater popularity. Drawing on a historical overview of the emergence of the 'participatory' turn in the sciences, the authors critically discuss the political possibilities as well as limitations inherent in the way citizen science is being framed today.

The plethora of definitions and classifications of citizen science is also taken up by Phillip Schrögel and Alma Kolleck in their paper "The many faces of participation in science: Literature review and proposal for a three dimensional framework". Starting out by recognizing the traceability of the many participatory formats construed under the banner 'citizen science' to some broad common denominator, they identify two 'main paradigms', viz., dialogues about science and doing science, respectively. They also argue that the academic discussion on citizen science is highly normative as it proceeds around the quality of data or process. As such their ambition is to provide a descriptive model, based on a literature review of conceptual frameworks and typologies in science governance and in participatory research approaches. This is done in order to modify Archon Fungs's model for participatory democracy to accommodate the epistemic and normative focus with the reach of participatory projects beyond institutionalized science. In this they aim to overcome the divides constructed as participatory science governance and citizen science that are confined to "the silos of their respective academic tradition". Their proposal is a three-dimensional model, contrasting it to the usual one-dimensional (normative) linear scales of hierarchy; thence they argue for participation in all aspects of the scientific process. The proposed model actually provides some tentative answers to the question posed by Cabasse-Mazel regarding how citizen science can be constructed by adjoining different agents and their activities. However, as the authors clearly state the model cannot cover what Cabasse-Mazel call the personal affective dimensions; however it will provide material for discussions on the normative statements so often heard in a current discourse of "pushing all participatory approaches to […] maximum openness."

Taken together, the five contributions on the epistemological and ontological diversity of citizen science all provide much needed perspectives for informed STS studies on the topic, both critical approaches as well as good arguments for engaging with these practices, Ultimately this might even lead to STS initiatives using citizen science as a potential powerful method for intervention. Thus, a new reflective theme can be introduced into STS, one which intervenes on an epistemological level in addition to the social level, hence accenting citizen science as a new social epistemology. What happens when STS engages with data collection and classification for epistemic justice, challenging established scientific knowledge? What does it mean to 'innovate methodologically' in order to perform 'engaged

STS' to change actual scientific practices (see Wylie et al., 2017)? Such enterprises definitely challenge STS to move beyond its ambitions to critically approaching the social and cultural composition of science and technology, and go further by now also creating 'politically relevant' (in search for a better term) scientific knowledge. Here, citizen scientists have shown that local problems, made invisible either by aggregated established data or simply ignored by institutional science, can be addressed by members of the concerned communities themselves, using innovative scientific methods. What can STS offer in such movements? This is a question we encourage the reader of this special issue to hold on to while reading the contributions.

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Engineering Publics:
The Different Modes of Civic Technoscience

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Abstract

Amongst the many modes of citizen science in the past years, civic technoscience has emerged. Whilst 'science' tries to explain the world, 'technoscience' tries to construct technological worlds. Whereas citizen science involves publics to contribute to data gathering and interpretation, civic technoscience involves publics in technological world making. By creating prototypes for engineering publics, civic technoscience expands the regime of technoscience into society. The article analyses three different cases of civic technoscience: a FabLab, a for-profit makerspace and a civic hackathon. These cases represent three approaches to civic technoscience: an emancipatory, an entrepreneurial and a science communication approach. Our ethnographic analysis reveals that these approaches need to be considered as ideal types: All our cases were shaped by an entanglement of emancipatory, entrepreneurial and science communication aspirations and practices.

Keywords: citizen science, technoscience, maker movement

Introduction

What happens when technoscientific practices enter the public sphere? How is technoscience performed as a public matter and how are publics themselves constituted by taking part in technological world-making? What kind of messy and unexpected technosocial relations are forged when technoscience becomes a mode of citizen science?

In this paper, we discuss and analyse different forms of 'civic technoscience' (Wylie et al., 2014) to understand new practices of 'material participation' (Marres, 2012) in the public sphere in which citizens collaborate to explore, invent, produce and use technologies in a public manner. During the past decade, people with different societal backgrounds and occupations have been increasingly invited to join the technoscientific enterprise: to experiment with (digital) technology, to develop new technological solutions for society's problems and to position themselves as engineering and innovative subjects.

In the first section of our paper, we discuss the distinction between technoscience and citizen science. Our second section presents three case studies that demonstrate different modes of civic technoscience situated in different organizational contexts. With these cases, we demonstrate that civic technoscience is already diverse and assembles different publics. We conclude with reflections on the role of civic technoscience in contemporary society.

Citizen Science, technoscience civic technoscience

Contemporary academic discourses on science and technology paint two very different pictures: On the one hand, we seem to have entered an 'age of technoscience' (Nordmann, 2011), dominated by emerging technologies and constructed in expensive laboratories that are inaccessible to the public. On the other hand, we seem to have entered an age of citizen science, shaped by novel forms of public participation in the scientific enterprise or varyingly as a 'democratization of innovation' (Hippel, 2005). We argue that technoscience as a contemporary mode of knowledge production is also becoming an increasingly public matter. We discuss this *expansion* of the *technoscientific enterprise* into the public sphere, thereby constituting new technosocial publics.

Citizen science: Extending the scientific enterprise

Within the "post-war social contract" (Jasanoff, 2003: 227) between science and the public, scientists were regarded as a distinctive truth class, sharply separated from ordinary citizens. Science communication was therefore informed by the deficit model, which suggested that the public needed to be educated about science by certified scientific experts. The divide between (scientific) experts and (non-scientific) lay people appeared to be a social *and* an epistemic one. The non-certified expertise of people outside of scientific institutions was largely neglected by professional scientists (Collins and Evans, 2002).

With the emergence of *citizen science*, however, public participation is expected to (re-)enter the heart of scientific knowledge production: scientific research (Finke, 2014). The term citizen science refers to projects that involve citizens not primarily in the mode of deliberative governance but as contributors to research, often enabled by digital infrastructures and mobile devices. In citizen science, project participants explore their environment, measure the noise pollution of their cities and reconstruct local histories.

Contemporary science policy discourses present citizen science as a tool of knowledge production *and* a tool to increase scientific literacy. They legitimize citizen science as a mode of doing science *and* as a mode of science communication (Bonney et al., 2009; Serrano Sanz et al., 2014). According to the narratives of citizen science, scientific research may again become a public matter. While the scientific enterprise in modernity was inherently linked to the scientific profession of certified experts, the socio-epistemic regime of citizen science aims to open research to non-professionals: "What was once a novel idea—lay people engaging in the scientific enterprise—is becoming mainstream" (Bonney et al., 2016: 14).

Citizen science is interesting for STS because it attempts to both *weaken* and *strengthen* science as a modern institution. Citizen science questions the 'jurisdictional claim' (Abbott, 2007) of science as a *profession* by allowing public participation in research. At the same time, it aims to extend the scientific *enterprise* of knowledge production into the public sphere. Empirical inquiries show, however, that citizen science at the level of specific projects is much more complex than the popular discourse on citizen science implies. Citizen science projects are very heterogeneous, they do not involve *the* public in a general sense and they assume different levels of expertise as conditions for public contribution. They are organized for different reasons and by different means, involving different forms of division of labor and hierarchy (Dickel and Franzen, 2016).

Technoscience: creating technology

In order to understand civic technoscience as a special mode of citizen science we need to first distinguish between science and technoscience. In recent years, some authors have begun to analyse the epistemic objects, goals and institutional foundations of technoscience as a specific and increasingly important mode of knowledge production in contemporary society – one different from science. This distinction is also an important way of differentiating citizen science from civic technoscience.

A rather general notion of 'technoscience', coined by Bruno Latour (1987: 174), has gained much prominence in STS. In Latour's (1987) view, science and technology have always been technoscience. They assemble social, material, technological and intellectual aspects to create and circulate knowledge. Science, however, 'purified' its messy embeddedness in sociomaterial networks through claiming for pure and universal knowledge. Following Latour, our contemporary world starts to question this work of purification. This questioning allows technoscientific innovations to become explicit activities formerly separated by notions of 'science' and 'technology' (Latour, 1993).

Nordmann (2011) proposes a more distinctive view of technoscience that we deem important to follow if we are to distinguish different modes of science and citizen science. According to Nordmann, there is an increasing dominance of a specific regime of *technoscience* within modern science and its relations to society. In Nordmann´s theory, the term technoscience describes contemporary strategies of knowledge production, legitimizations and relations to the natural and social world that focus on the creation of novel technological capabilities. These strategies differ from the strategies and aims of 'science' that focuses on the creation of better theories. Whereas the aspiration of the scientific enterprise was the discovery of truths, the aspiration of technoscience is the production of technological innovations. The contemporary notion of technoscience gained prominence within emerging fields such as nanotechnology, biotechnology, computer- and neurosciences. Common features of these fields are rationalities of *engineering*, which are translated into other academic fields, social contexts and societies. A prototypical example of this is synthetic biology, which tries to apply an engineering approach to biology in order to design novel biological systems and, in turn, to radically alter societal relations to nature. However, technoscientific rationalities also increasingly enter everyday life, politics and the public sphere. Part of the regime of technoscience is the existence of diverse 'sociotechnical imaginaries' (Jasanoff and Kim, 2009) that entangle technoscience with societal problems (Grunwald, 2014; Nordmann, 2016). Technosciences promise to reconfigure the world at micro and macro levels, to transform whole societies into novel post-human 'megamachineries' (Mumford, 1970) and to reengineer life, matter and information at the level of genes, atoms and bits (Roco and Bainbridge, 2003). From the perspective of technoscience, everything can and should be designed and transformed through technological inventions and interventions. This technoscientific imperative is being constructed and enacted through various futuristic discourses that are central to how technoscience is legitimated and entangled with publics and politics. Thus, much of the public appeal of mainstream technoscience is based on grand promises about how new technical capabilities might turn into innovations and redesign society (Dickel and Schrape, 2017; Sand and Schneider, 2017).

Civic technoscience: Extending the technoscientific enterprise

It might appear as if technoscience and citizen science refer to distinct and mutually exclusive socio-epistemic regimes: While institutionalized science reconfigures itself (partly) as (explicit) technoscience, the 'traditional' scientific enterprise is revitalized and extended through lay participation in the mode of citizen science. This simplified view also corresponds to the self-descriptions of some citizen science protagonists. Finke, for example, conceives of citizen science as a way of *preserving the scientific enterprise* in the face of an institutional science system that, due to recent economic and political pressures, is increasingly more interested in the production of innovation than in the production of truth (Finke, 2014). Both regimes imply very different roles for the public: While the scientific enterprise of modernity imagines the public as citizens in need of education (about scientific truths), technoscience imagines the public as users of technological innovations. The public's role is restricted to either embrace the imaginaries of technoscience or to engage in critical discourses (Nordmann and Schwarz, 2010; Gaskell et al., 2005).

To transcend such dichotomies, Wylie and colleagues offer the term 'civic technoscience' by which they designate sociomaterial settings and strategies that "sustain a civic research space external to the academy and where non-academics can credibly question the state of things" (Wylie et al., 2014: 118). Although the authors focus on specific technoscientific practices, this is not reflected in their definition. Following Nordmann's argument for a strong characterization of technoscience, we restrict the notion of civic technoscience to civic research with a focus on the creation and exploration of technologies. This resembles a growing literature on a 'democratization of innovation' (Hippel, 2005). However, the key difference is one of framing and perspective. The framing of democratized innovation is based upon an economic logic of technological development. The framing of civic technoscience highlights the public and civic logics that are becoming visible if technologies are not simply seen as products and the involved people are not simply seen as users or consumers.

Several trends and transformations of contemporary societies have contributed to the emergence of civic technoscience. The public sphere has been massively transformed through the Internet: Through various platforms, diverse publics have come into existence (Castells, 2002). 'Openness,' 'transparency' and 'collaboration' have become important political terms under the condition of such digitised publics (Tkacz, 2015). In contemporary societies, many if not most futures and transformations are being considered as consequences of (digital) technological innovations (Urry, 2016). As a paradoxical effect of technoscientific imaginaries, many novel technologies have become public issues which contributed to the delegitimization of certain forms of certified expertise. All kinds of public engagements, policies and publics are formed and transformed into novel technosocial arrangements that are being forged into existence with the purpose of involving all of society in technoscientific matters (Lösch and Schneider, 2016; Nordmann, 2016). The recent proliferation of 'material participation' (Marres, 2012) must also be considered as a proliferation of technical objects. Technological artefacts in qualitative variety and quantitative scale are acquirable and accessible on almost global scale. In particular, *digital* objects are increasingly being perceived and desired as malleable, connectable and unfolding things (Knorr-Cetina, 1997). Open source software development combines these transformations and became an example for many aspirations in civic technoscience. In open source projects, online communities develop technical objects and publish documentation, blueprints and design files online to foster the sharing of technical knowledge.

Civic technoscience enables collective public experimentations with (often digital and open) technologies, which includes the sharing of technological knowledge and the aspiration to develop technological solutions to society's problems with and by publics. In order to investigate how the tensions between publics and institutions — which became already apparent in citizen science — also shape and affect civic technoscience, we will now focus on specific local publics. How are both civic technoscience and its publics produced? What are the similarities and differences of specific instances of technoscientific participation?

Civic technoscience in practice

The following section presents three variants of civic technoscience. The selection of cases rests on a comparison of dissimilar instances of civic technoscience in Germany. We are starting with a case reflecting an *emancipatory approach* to technoscience: a grassroots FabLab that aims to facilitate civil society engagement with digital fabrication. We then introduce a for-profit makerspace that is part of an entrepreneurship center of a leading technical university, demonstrating an *entrepreneurial approach* to public involvement. We close our presentation of cases with the analysis of a civic hackathon, carried out by on organization for public understanding of science and technology, reflecting a *science communication approach* to civic technoscience.

The analysis is the result of extensive ethnographic work. We took part in the typical activities of the respective fields and conducted interviews with a variety of actors. In all cases, a distinction between a core group of 'organizers' and 'participants' was visible, thus we talked to both groups. We also discussed our findings with the actors in the respective fields. Before and during our participant observations, we examined documents like websites and flyers to understand self-descriptions and self-displays. Attention was also given to the material infrastructures as well as to the geographical and institutional environment in which the activities took place. In order to understand the similarities and differences of the cases, we analysed each field according to the following dimensions:

a) *Governance mechanisms*: How is participation enabled and organized? What kinds of actors are involved? What strategies are deployed to enable public engagement?
b) *Dynamics of inclusion and exclusion*: Who should, according to the self-descriptions of the field, be included in the activities? How is inclusion of publics facilitated? What groups are excluded (be it by means of discourse or practice)?
c) *Spatiality and temporality of engagement*: Where does participation take place? What is the role of local infrastructures? Do the activities result in a long-term engagement of publics in civic technoscience (be it inside or outside of the boundaries of the respective field)?
d) (*Blurring of) boundaries between experts and lay persons*: Does the field problematize established distinctions of experts and lay persons? Are some boundaries blurred and/or do new ones emerge? Who counts as an expert in the first place? Is the jurisdictional claim of certified experts challenged?

A Grassroots FabLab

Grassroots organizations have proven to be particularly relevant to transform scientific practices (Jalbert, 2016). Thus, our first case is a 'grassroots' FabLab in Germany that has been run by voluntary members since 2014. FabLabs, short for 'fabrication laboratories,' have become particularly prominent during the last decade as a novel form of workshop that is accessible to publics and which is mainly based around machines and processes of 'digital fabrication.' FabLabs define themselves through working with at least a set of computer numerically controlled (CNC) machines, such as 3D printers, laser cutters or milling machines, although many FabLabs offer other tools as well. The concept for FabLabs was initially conceived at the Media Center of the Massachusetts Institute for Technology (MIT) around the year 2000, where the technoscientific aspirations to control matter digitally, together with a form of science funding that fostered engagement with society, created the idea of making CNC machines publicly accessible. This move was particularly inspired by an emerging imaginary of highly capable digital machines available to individuals. This led the researchers to speculate about a "digital fabrication revolution" that would enable everyone to make anything anywhere, just like the personal computer enabled the decentralised production of immaterial goods (Gershenfeld, 2012).

Although in the first years, the initial FabLabs had close ties to MIT and thus to institutionalized and elitist technoscience, this changed dramatically around 2010. Troxler (2014) describes how, in the Netherlands networks of researchers, artists and tinkerers wanted to start FabLabs without formal relationships to MIT and also on a more affordable basis. The first 'grassroots' FabLab was thus established by a community of artists and social activists with a budget of €5000 in a town in the Netherlands (Troxler, 2014). As of 2018, there are around 1300 FabLabs across the globe, variously run by a hosting organization, as a company or as a member-based organization (Fablabs.io, 2018). Formal ties to MIT are no longer necessary to start a FabLab. It is rather expected that each FabLab hosts a similar set of machines and subscribes to particular guidelines, the 'Fab Charter.' Already at MIT but increasingly so with the spread of grassroots FabLabs, a form of public and participatory expertise has been enacted by these workshops. Their governance is shaped by the cultural ethos of making digital fabrication accessible to individuals.

In 2013, a group of citizens of a German city participated in a project to establish a grassroots FabLab. In early 2014, the FabLab opened its doors and, at the time of writing, became a member-based non-profit organization with about 150 members who pool their resources—what is called a 'Verein' in Germany (essentially a club or association). In a room of around 80 m^2, the organization offers its members (and once a month also non-members) access to several 3D printers, a laser cutter, a CNC mill, electronics and common tools. Members pay a fee of around €20 a month and elected a board that manages the association. Mostly, the lab is used by its members to pursue individual 'hacking,' 'making' or other do-it-yourself (DIY) projects such as furniture, lighting, small robots and, particularly important to many of its members, building and improving CNC machines, especially 3D printers. Most of the members are hobbyists and technology enthusiasts with a professional background in technology. However, most also see the FabLabs as separate from their work and as a space for leisure and civic involvement. On an informal level, inclusion and exclusion is largely based on these cultural and habitual aspects of the members who voluntarily choose to associate with like-minded others.

In addition to being an organization for interested individuals, the FabLab offers special events and outreach courses, e.g. to school kids, that convey technical skills and enable people to explore digital fabrication technologies. The education about and the promotion of digital fabrication is one central area and an important goal for the organization. Similar to other civil society organizations that are member-based, e.g. sports associations, the FabLab hosts facilities for particular (technical) practices and provides teaching and a space to socialize. Thus, while the FabLab typically reaches out to people that are interested in technology and tinkering, it addresses a wider public through its special events. All these activities are based on an imaginary of the desirability of digital fabrication and its further dissemination. However, most of the digital fabrication processes in the lab are rather difficult to operate and mastering them requires a lot of time. The FabLab thus assembles experts in digital fabrication at special times, such as in courses or public events, who try to share their knowledge with others. Therefore, while the core members (who typically have self-trained or professional technical expertise in digital fabrication) participate on a regular basis, there are more spontaneous and irregular forms of participation by other groups. Expertise is often explicitly questioned and the aim of making technologies accessible to others gives meaning to the educational aspirations of the organization.

In tight entanglement with the spread of FabLabs beginning around 2005, the 'maker movement' emerged and began to grasp the imaginations of hackers, DIY enthusiasts, the media and even policy makers. Considering the spatial and infrastructural organization of this and other FabLabs, one needs to see these organizations in relation to the global assemblage of the maker movement. This global network has enabled local labs and practices through networked and digitized forms of participation in technical knowledge as well as social imaginaries of open source technologies. The term 'maker' was first used by a publisher for computer and software literature in order to reach out to a more diverse audience of people interested in tinkering with technology and to avoid the negative connotations that sometimes accompany the term 'hacker.' The respective magazine and trade fairs that included all kinds of DIY projects quickly helped to turn 'making' into an umbrella term for various DIY practices that increasingly used the Internet to coordinate and share ideas. In addition to creating an imaginary of decentralised and user-led innovations through makers, within this movement organizational settings emerged. 'Hackerspaces' —mainly concerned with software and computers since the 1990s — started to include other technologies. Spaces that sought to emphasize their association to the maker movement labelled themselves 'makerspaces'. The maker movement turned making into a public issue and it also helped to build and legitimize FabLabs – and as we show below, other organizations as well. FabLabs can be viewed as a specific subset of makerspaces specially aimed at making digital fabrication public.

The publics of open source projects have been particularly important for the technoscientific practices within the investigated FabLab. Again, entangled with the rise of the maker movement and FabLabs, there has been a spread and increasing diversity of open source projects aiming at developing technology. Significantly, in 2004, the open source 3D printing project 'RepRap' started to publish building instructions for such machines in the public domain. By now, the project has laid the foundation for hundreds of relatively inexpensive 3D printer designs. It also helped to create a 3D printing hype by having made visible and graspable the idea of individually usable and affordable 3D printers for 'everyone'. There are many more of those projects where Internet-coordinated collectives design technologies and publish explicit knowledge under public licenses, e.g. creative commons licenses, to share technical knowledge. These have been highly relevant to the existence of the investigated FabLab. On the one hand, most of the core members of the lab became interested in FabLabs and gained expertise in digital fabrication through their engagement with open source projects – mainly 3D printing. On the other hand, much of the digital fabrication infrastructure in the FabLab is based on open source designs and was partly built by the members themselves. This dramatically lowered the cost of this technical infrastructure as compared to similar industrially applied machines. We might say that these open source projects assemble individuals who foster and learn a form of technical expertise with an ambition to publicize and share knowledge.

Taken together, civic technoscience in the FabLab has several dimensions. There is the member-based organization that aims to facilitate experimentation with digital fabrication machines. The people running this institution regard it primarily as a civil society organization, which tries to empower citizens. These citizens are imagined as actors who are willing to become empowered through digital fabrication and invest their time to do so – spreading digital fabrication is seen as their civic duty. Furthermore, the FabLab assembles wider publics that centre around digital technologies and DIY practices and that have contributed to turning making, open source, and digital fabrication into public issues and emancipatory paths to reconfigure technoscience (Dickel and Schrape, 2017; Schneider, 2018).

A makerspace at a university's entrepreneurship centre

The second case presents results from ethnographic fieldwork that has been conducted at a makerspace at a German university. We show that, although this makerspace seeks to attract an unspecific, heterogeneous public, its organizational structure and socio-technological setting nevertheless puts limitations on the participation and engagement of these same publics.

Makerspaces are declared to be 'open to everyone,' allowing each individual to gain experience with professional machine tools, materials and practices of design and engineering. This turn towards collective spaces of fabrication is often seen as an act of empowerment, rendering those actors more integrated and proactive that have so far been excluded from engineering practices.

The makerspace this chapter draws on is closely affiliated with a university's entrepreneurship center. While some makerspaces – like the FabLab described above – are collectively governed and organized by their users (bottom-up), the makerspace here reveals more hierarchical structures (top-down). The team comprises a general manager surrounded by a core team that runs the workshop, its infrastructures and events, develops marketing strategies and builds collaborations with companies or public institutions. The makerspace has additional crewmembers and trainers who primarily work in the workshop itself, maintaining the machines and storage rooms, as well as teaching and providing the users with technical knowhow and skills. Based on interviews we conducted during our fieldwork, the makerspace team regards itself as a business and service provider (Interview, Manager, January 2016). Unlike other shared workshops, the makerspace does not rely on donations. Rather, it has developed an economically oriented business strategy that attempts to commercialize working spaces for companies, firms, smaller start-ups and private users in order to let them build, design and prototype their project ideas. The workshop is equipped with professional and high-tech machine tools that are often also utilized in industrial manufacturing. Their facilities range from 3D printers, laser cutters and industrial sewing machines to water jet cutters, metal or wood band saws and other CNC machines.

In light of their close cooperation with larger (industrial) companies or events like 'makeathons', the makerspace's main goal in terms of public engagement is to extend its services to as many different groups and actors as possible. Although it regards itself as a service provider, the makerspace does not work as a 'manufactory' for customers. Rather, at the core of their service stands the provision of the workshop itself, the maintenance of the machines and introductory courses. In the following, we will describe how specific governance mechanisms organize and engage with the public by explicitly focusing on the makerspace's courses, the use of the machines and their user groups. We also show how the dynamics of inclusion and exclusion of this present case of civic technoscience challenge the potential of integrating a wide and heterogeneous public that the makerspace has sought to address.

To begin with, the makerspace works on a membership basis. Companies, start-ups, student groups or private users have to apply for a membership that permits them to enter the workshop. In order to use the machines and tools, members have to attend introductory courses that require paying additional fees. In contrast to 'bottom-up' makerspaces, this case offers specialized and professionalized courses being run by trained crewmembers who introduce and explain the respective machines. The actors involved thus seem to regard their contribution to a wide *public engagement* in the act of teaching and distributing technical knowledge amongst every member. The courses usually run for up to two to three hours, where participants learn specific technical skills, for instance, how to build a bottle opener out of metal. During the course, participants are equipped with material, instruction papers and safety glasses. All these conditions aim to develop and improve the user's skills and crafting abilities. Only after having attended the course (at least once), members are permitted to autonomously use the machines for their individual purposes.

Participation in the makerspace is thus initially organized and guaranteed by the courses and the possibility to apply the gained knowledge in order to autonomously use the machines. The courses are meant to address a heterogeneous, unspecific public by claiming to invite *everyone* to work and take part in innovation and engineering processes. Introductory courses and instructions inform those participants who have not yet acquired concrete practical experience about how to craft and construct objects. Moreover, they seek to create an atmosphere that puts every member on the same level of expertise and knowledge. Accordingly, the makerspace seems to attract and include a wide, heterogeneous public, consisting of professional engineers, hobby-tinkerers and actors without any experience. All of them play an important role in the (co-)production of technological artefacts, as well as in the process of generating innovation and knowledge about it. Consequently, the public in this field of civic technoscience cannot only be seen as one becoming educated (the usual public of science) or one using or deliberating technological innovation (the usual public of technoscience), rather it operates as one that is *itself* active in engineering processes.

However, while the public of makerspaces is sought to be diverse, our research revealed that this is not always the case. Trainers with expertise and skills, as well as the business model (which rests on membership fees) and the socio-material setting (that includes highly professional and expensive machine tools) already pre-define the kinds of users that can access the investigated space. During our ethnographic study, we experienced particular dynamics of exclusion when talking about the function of 3D printers:

> I walk around the workshop and look at all the different machines in the 3D printing area. One of the bigger machines is currently working and I wonder what it is exactly printing. I ask a crewmember who is just about to check the machine. I feel a bit clumsy and illiterate when asking about what it is printing. She turns around and replies in an astonished manner: "You don't

> know how this machine works?!" Now I feel even more unsettled since I thought I articulated my question clearly. I stumble "No, I mean, yes… But I wanted to know what the 3D printer actually creates?" She talks about her project and mentions a chair that she likes to produce. I realize how she still loses interest in keeping the conversation going because after a few sentences, she turns around and seems to concentrate on the screen. (Field notes)

This extract from our ethnographic field notes demonstrates how crewmembers that are familiar with the respective machines seem to expect a certain level of expertise and knowledge from the user beforehand. In this particular situation, the ethnographer had little knowledge about 3D printers and was quickly viewed and approached as a non-expert. While the makerspace is claimed to be a place for everyone without any expertise, we can yet see how social expectations entangled with the professional quality of the machines actually construct a more specific public, namely one, which already possesses technical expertise.

This case has moreover revealed that it is primarily those actors with a concrete idea and project plan that appeared to benefit most from the workshop. During the ethnographic study, our researcher attended courses at machine tools that, for instance, taught her how to draft and produce a bottle opener. We observed that for some participants it was difficult to know directly how to craft construction plans that were required in order to further proceed within the course. A mere introduction into the type and use of a machine did not immediately help since the courses demanded additional knowledge and expertise — for instance, when choosing the right material or crafting out construction plans and drawings. As follows, in addition to the dynamics of exclusion that were enacted by the actors' expectations, the structure and pre-requirements of the courses similarly contribute to shaping and pre-defining a more specific public. Moreover, the types of projects to be drafted directly in the workshop were already constrained (if not hindered) owing to membership fees and the concurrent necessity of pre-preparation. Consequently, this form of civic technoscience can only address and integrate those publics that already possess technical familiarity and expertise, an interest in technology and crafting, as well as concrete project plans.

It is therefore not surprising that during the fieldwork, the makerspace was mainly used by start-ups, industrial companies and professionals who work in the field of engineering or innovation management. The users who were less familiar with crafting, tinkering or manufacturing were, in turn, considerably fewer. Moreover, according to a private user, "there are so many members from the makerspace walking around. Like staff-members […]. I haven't seen that many students so far but also not really old people" (Interview, User, May 2016). This might seem to be paradoxical, considering the fact that the makerspace is located right at the university campus, and one might expect that a great number of students would use the makerspace facilities. Nonetheless, due to factors like membership fees, pre-existent knowledge or general interest, the makerspace failed to equally integrate younger user groups like students. This, again, underpins our conclusion that the public attracted here seems to be a rather exclusive one, primarily involving those actors who possess specific forms of expertise and business interests. As our ethnography has consequently shown, in most of the cases the involved actors running the makerspace were not aware of these dynamics. This relates to the entrepreneurial approach of the makerspace, which preconfigures the kinds of publics it aimed to attract.

A Civic Hackathon

In our last case study, we analyse a civic hackathon focused on urban innovation and sustainability. The civic hackathon (Schrock, 2016) was conducted in a major German city in 2015 and lasted two days. Compared to the cases we have already presented, this civic hackathon was not organized by a non-profit organization or a company but by an organization for public understanding of science and technology with close ties to the German Federal Ministry of Science and Education (BMBF). It usually organizes discussions and exhibitions dealing with science and technology. In this special case, the institution collaborated with a non-profit organization (NPO) that advocates open knowledge and open data and promotes and supports (digital) civil rights. Therefore, one focus of the hackathon was on topics like freedom of information and open science. After the event, the groups were given the possibility to develop their ideas at so-called 'Citizen Science Labs' (regular meetings at the already existing open science organization's labs).

During the last decade, it became popular to arrange civic hackathons for enhancing science policy and science communication 'off the beaten path'. Hence, when proposing this particular event to the ministry, both organizations used the rhetoric of hacking and making to describe their approach to socio-technical innovation. Adapting this rather unconventional event was a challenge for the institution of science communication. However, it was also a possibility not only to discuss technoscientific issues in public but also to activate citizens to become participants in the generation of technoscientific innovations themselves. The collaboration with the open science NPO enabled the public engagement organization to interact with citizens in a completely new way that broke with their own routines (Interview, Organizer 1, July 2015). The hackathon assembled a special public and we will show why, at the end, this public was more exclusive than the organizers had originally planned and sought.

Both organizations aimed to generate a public to create innovations for a more open and sustainable city within two days. The event started on a website where interested citizens had to sign up for the respective hackathon in their city and chose one participant category (programmer, designer, city enthusiast or scientist). These categories reveal that the initially addressed public was imagined to consist of certified scientific experts as well as citizens with expertise in hacking (programmers) and making (designers) – but also inexperienced people who were motivated to participate because of a desire to improve urban environments (city enthusiasts). Only citizens with access to the Internet were able to subscribe to the event – so this registration by itself constituted a first moment of exclusion. During the registration process, the participants were already encouraged to formulate and discuss ideas on how to improve their city and how to publish them on a digital platform. Examples of the discussed ideas were rooftop gardens or open bicycle maps. Later on, these ideas served as 'icebreakers' during the pitching session, an important part of the civic hackathon, and at the same time as the visualization of differences in hackathon experience.

The event itself took place at a biotech start-up located in a backyard in an alternative and multicultural district of the city. The space was decorated with vertically hanging plants and hosted a large coffee bar, all of which is in line with the typical gathering spaces of the creative class in the respective city. Still, the start-up was not able to provide the 'right equipment' for the hackathon such that organizers had to arrange the necessary technological apparatuses. It is important to mention that the 'right equipment' was defined by the organizers themselves. Using the existing infrastructure at the individual locations, they created a hacking place at the biotech start-up with Arduino kits and modelling clay so that the citizens could experiment without instructions. The provided 3D printer as well as the sensor set was introduced and curated by experts who answered questions and provided practical help for laypersons. The participating citizens were encouraged to access the technology, to print prototypes or to work with sensors.

The day started with the participant registration in the morning where everyone received a coloured sticker that marked his or her particular group affiliation. Red stickers, for example, marked the group 'scientists.' After welcoming the participants, the theme of the event was introduced by 'Lightning Talks' where speakers discussed different topics such as classical citizen science, but without building the connection to the specifics of civic technoscience. During the following pitching session, the participants were asked to communicate their ideas for improving the city through short presentations in order to attract possible collaborators. We could observe that some participants were quite experienced in these formats, especially participants belonging to the hacker community. They had the special expertise about how to pitch properly, so that people became interested in working on their ideas. Other participants had problems defining their goals or communicating their ideas to the audience. During lunch break, the participants were asked to form hacking groups that were expected to work together for the following two days. Not everybody was able to find a group, or in other words, they did not have the right expertise to orient themselves in the informal procedure of a civic hackathon. Therefore, the process of pitching and group finding can be seen as the *biggest moment of exclusion*. The organizers acknowledged this problem. Hence, they moderated the group finding process in the following year and helped people to connect to other participants.

After building groups (or not), the hacking started after the lunch break. Working on their chosen projects in small groups, some group members programmed while others experimented with the sensor sets, and a few also used the 3D printer to try to create models – always supported by a 3D printing expert. On day two, the number of participants was scaled down, meaning that, for example, two groups only had one member left. Following a second working session with the remaining groups, the groups presented their results and a jury selected the three best projects. The winners each received a coupon for hardware acquisition (e.g. sensor technology, Arduino kits, etc.) worth €500. Despite having been originally announced by the organizers, none of the invited representatives from the city showed up. Six digital and non-digital prototypes were praised as solutions for urban problems like the lack of cycle paths and global problems like air pollution.

However, the hope that the hackathon might serve as a starting point for a long-term engagement activity did not work out. Therefore, the officially communicated goal of this event was not achieved. Nevertheless, some citizens were able to experiment with sensor kits or used 3D printers for the first time in their lives and reflected upon technological innovations for sustainability. Hence, a few unexperienced participants gained some technological knowledge associated with hacker or maker communities (however, scientific knowledge – e.g. comparable to an academic engineering curriculum – had not been transferred). All in all, we observed that it was generally helpful to already possess experience with hackathons in order to endure the two days of insecurity around the idea-finding- and realizing-process.

Contrary to the aspirations of the organizing institutions, the assembled public was neither long lasting nor diverse. Most of the participants were people who were already part of the hacker or maker community. Only a few citizens stayed until the end and got through the hacking process. Also, as of now, the groups no longer work together. Thus, the hackathon did not achieve its original objective to create sustainable solutions for the city. Instead, it created an awareness for civic problems in another way – that is, through creating prototypes. Therefore, we assume that civic hackathons like this generate a temporally limited, unstable but affected public. This public is still exclusive and consists of participants with and without expertise in the field of hacking and making – but all of them gain and produce technoscientific knowledge while working on their prototypical innovations. The societal impact of this knowledge production should, however, not be overestimated because it is limited by the specific social, spatial and temporal elements of the format. Yet, a central discursive function of the event was the communication of technoscience: It positioned socio-technical innovations as possible solutions for urban problems.

Discussion

Our case studies reveal that civic technoscience is performed in heterogeneous ways. The three cases differ substantially in terms of governance mechanisms, dynamics of inclusion and exclusion, spatialities and temporalities and the (blurring of) boundaries between experts and laypersons.

Governance mechanisms:

The FabLab as well as the entrepreneurial makerspace are both membership-based formal organizations, but very different ones: The FabLab was established bottom-up, through citizens inspired by ideas of hacking and making, whereas the makerspace is rooted in the innovation strategies of industrial and academic organizations. The FabLab is a club, collectively governed by its members. The makerspace operates as a business with clear boundaries between employees (working for the organization) and users (paying membership fees). In all cases (including the hackathon), formal organizations provide platforms for projects developed by persons outside the respective organizations. Hence, the success of all of these different institutionalizations of civic technoscience depends on the attraction of committed publics. This became especially apparent in the case of the hackathon, because it needed to assemble a crowd capable of developing prototypes in a very short timeframe. The main governance challenge of such a format is to give participants freedom to experiment while keeping the event at the same time structured and focused.

Dynamics of inclusion and exclusion

All three cases are shaped by a discourse of universal inclusion: Everyone is invited, anyone can participate. The public constructed by invitations, public statements and promotional materials was therefore a very general one. Moreover, the events and spaces were designed as open platforms. Our ethnographic observations, however, revealed more complex dynamics of inclusion and exclusion. In none of the cases were groups of people explicitly excluded. The exclusion was rather implicitly inscribed into the infrastructures and organizational formats. In each case, an already existing technical expertise allowed participants to integrate themselves into civic technoscience and to contribute to the development of ideas and projects. The investigated makerspace was the most exclusive instance of civic technoscience, while the FabLab – corresponding with its strong focus on education – proved to be the most inclusive one.

Spatialities and temporalities

Participation in civic technoscience takes place at specific places. In all three cases, these places were designed as workshops, equipped with tools for collaborating, hacking and making. These workshops were more or less professional, ranging from just a few tools in the case of the hackathon to a very expensive infrastructure, which fulfils industrial standards in the case of the investigated makerspace. The respective infrastructure has a strong influence on the practices and constitutions of publics as well as on the governance of the organizations. In all cases, the local workshops were entangled with larger networks (e.g., open source and maker communities), positioning the specific places as nodes and instances of a 'movement' of civic technoscience. Even the hackathon had long-term aspirations as the prototypes were originally imagined to be further developed in 'Citizen Science Labs'. It became clear that an ongoing commitment of participants as well as stable financial resources are crucial factors for the sustainability of civic technoscience.

(Blurring of) boundaries between experts and laypersons.

Citizen science discourses often imply a blurring of boundaries between experts and lay persons. Expertise should be reconfigured and redistributed by novel forms of public participation based on open digital and material infrastructures. In all our investigated instances of civic technoscience, we could observe a sharing and pooling of technoscientific expertise. All cases comprised of educational elements in which experts translate technoscientific knowledge to an assembled public. This also reveals that the distinction of experts and laypersons does not vanish in civic technoscience. However, the communication structures did not conform to the 'deficit model', because in all cases the assembled publics were either addressed *as experts* for specific issues or addressed as laypersons which might *become experts* by taking part in civic technoscience. In fact, we could observe participants who became experts in specific areas by participating in civic technoscience. The limits of a diffusion of expertise rests in the implicit exclusion mechanisms in all three cases. We conclude that a pre-existing technical familiarity, including cultural and habitual aspects, is an important factor for participation in civic technoscience. It increases the chances for people to participate in the first place and to participate in a substantial manner.

Conclusion: Civic technoscience between emancipation, entrepreneurship and science communication

Just as citizen science aims to open and extend the scientific enterprise to the public, civic technoscience aims to open and extend the technoscientific enterprise. And just as technoscience is shaped by imaginaries of future technologies, civic technoscience is shaped by the imaginary of a democratization of engineering and design. Hence, a discourse of inclusion and extension is very visible in all three cases: The workshops *invited* a general and unspecified public to participate. They all expressed the ideal of a technological culture in which everyone can and should take part in designing our world by means of tinkering, hacking, making and engineering. Our case studies show, however, that these aspirations of universal inclusion are limited by the design of the respective participatory formats as well as by the expertise of the participants.

Civic technoscience as a situated *practice* might not fulfil the utopian expectations of 'making' and 'hacking' as technosocial *imaginaries*. It does, however, imply an opening of specific technological black boxes. Civic technoscience makes practices of hacking, tinkering, making and engineering (more) public — be it in the service of political, economic or educational goals. To this end, new infrastructures (like makerspaces), technologies (like 3D printers) and events (like hackathons) are constructed. Thus, the publics of civic technoscience are themselves engineered by socio-technical means: They are assembled as *parts* of the contemporary technoscientific regime — as *transformative* parts that should make this regime more open, inclusive and/or innovative. Such transformative efforts, however, are launched by different actors that are differently positioned within the regime, resulting in different ambitions and practices of transformation, some of which tend to reproduce existing closures.

- The grassroots FabLab follows an *emancipatory approach* to civic technoscience. It assembles heterogeneous publics in which digital networks are entangled with localized practices. The FabLab itself is created as a tool for empowerment and public education. It is designed as a civil society organization that aspires to make digital fabrication public. This is also reflected in the bottom-up governance structure and an explicit reflection and problematization of the distinction between experts and laypersons.
- The entrepreneurial makerspace follows an *entrepreneurial approach*. The makerspace takes the form of an enterprise focused on fostering innovation. In this case, making technology and knowledge production public is not primarily a political aim but a business model. Despite its self-description as being open for everybody, the public of the makerspace is much more exclusive, consisting primarily of professional engineers and start-ups who use the infrastructure of the workshop. The makerspace offers them the opportunity to use rapid prototyping machines and to collaborate outside of the confinements of their organizations.
- The civic hackathon represents a *science communication* approach to civic technoscience. The hackathon is part of a governmental science policy and public relations strategy. Its aim was to develop prototypes for urban innovation. While the hackathon was not successful in generating a diverse and long-lasting public, the exercise in public prototyping produced an increased public familiarity with specific technologies and promoted public prototyping as a tool for addressing societal and sustainability problems. Furthermore, it endorsed the idea that public problems can be solved by means of technoscience as a public activity.

In the three approaches, civic technoscience "question[s] the state of things" (Wylie et al. 2014, 118) quite differently. In the entrepreneurial mode, dominant production and innovation regimes are problematized. In the science communication mode, local and global societal problems are addressed by technological means. In the emancipatory mode, the problematization extends to overarching political issues and social structures.

Our ethnographic research revealed that the three modes need to be considered as ideal types. We propose that *civic technoscience is typically shaped by an entanglement of emancipatory, entrepreneurial and science communication aspirations and practices*: Instead of sharp separations between these modes, we could observe nuanced differences in our cases. While the FabLab positions itself as a civil society organization, it also functions as an incubator for entrepreneurial ideas. It likewise engages in the communication of technoscience by educating publics about novel technologies. At a first glance, the entrepreneurial makerspace might be considered purely as business (and maybe not as an instance of civic technoscience at all). However, its very business model depends on the assemblage of publics interested in using and developing technologies. The discourse of "democratizing innovation" (Hippel, 2005) is not just 'talk'. It is constitutive for the self-understanding of the organization. Moreover, its communication strategies rest on the notion that (digital) fabrication technologies become accessible for the public. Hence, it also engages in the communication of technoscientific possibilities. The hackathon worked primarily as a science communication exercise. However, its promise of generating innovation through an emancipatory bottom-up approach was constitutive in attracting a public in the first place.

In all these cases, publics are not restricted to the role of consumers who buy and apply technologies. They are also are not positioned as entities that just need to be *informed* about technoscientific knowledge (the public understanding of science paradigm) or addressed as a variety of stakeholders that participate in critical discourses and *deliberations* (the public engagement paradigm). Rather, in civic technoscience, heterogeneous publics revolve around the co-production of artefacts. Whereas citizen science questions the jurisdictional claim of professional science over the production of facts, civic technoscience (in all three cases) questions the jurisdictional claim of professional engineering over the production of technological artefacts. It is a mode of knowledge production as well as a tool to increase technoscientific literacy. Publics in civic technoscience are not primarily formed to address technoscientific *problems* but to create new technoscientific *solutions* (for problems created or not created by technoscience). They are assembled as "performing audiences" (Andersen and Knudsen, 2016: 448), which themselves take part in the invention and production of technologies as well as new techno-social worlds.

Civic technoscience does not only imply a gathering of publics engaged in engineering. Civic technoscience needs to be also understood as an engineering of such publics themselves. It is realized by a socio-technical assembling of citizens, which are expected to perform (more or less specific) functions. Our cases demonstrate that this engineering of publics does not produce a general democratization of engineering and design. Rather, it produces situated publics of both certified and non-certified experts in different social contexts and settings that openly experiment with technologies. From the organizers' position, the specific settings and events of civic technoscience are themselves conceived as prototypes of participatory machines. The organizers act as 'social engineers' who aspire to learn from these prototypes — in order to build new upgrades and updates for FabLabs, makerspaces and hackathons. It is not by realizing utopian imaginaries but by creating prototypes for engineering publics that civic technoscience expands the regime of technoscience into society.

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Citizen Science Across a Spectrum: Broadening the Impact of Citizen Science and Community Science

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Abstract

Environmental protection as a movement is broadening to both invite and require the participation and energy of everyone, including federal agencies, local governments, activists, and enthusiasts. There is evidence that institutions and agencies are moving towards more inclusive visions of their missions, and citizen scientists and community scientists are motivated to be involved. Citizen science and community science, approaches rooted in non-traditional partnerships and diverse participation, are a strong approaches to science, and they are especially strong approaches to a wide range of outcomes with direct impacts on the protection of the environment, from civic engagement to enforcement action. In this discussion paper, we propose a spectrum of engagement that defines opportunities for citizen science and community science beyond the participation of volunteers in institution-driven or scientist-driven research; we also provide examples of projects and efforts that have led to outcomes for each of the spectrum categories. Citizen science and community science represent a more inclusive version of science and provide a model for embracing truly collaborative environmental protection, as well.

Keywords: citizen science, community science, environmental protection

Introduction

Citizen science and community science are thriving. Millions of people are participating in and starting thousands of projects (Funk et al., 2017; Scistarter.com) that are contributing to scientific, educational, and advocacy outcomes. The impact of citizen science on science is remarkable and still growing; the use of the term 'citizen science' in scientific publications is growing exponentially (McKinley et al., 2015). For example, central claims about bird migration and climate change have been shown to be based in large part on data from citizen science (Cooper et al., 2014).

The contribution of citizen science to science continues to be demonstrated, and we argue that the contributions of citizen science and community science to environmental protection beyond research is unrealized and potentially even more impactful. *Citizen science* is the involvement of the public in scientific research and in its traditional form crowdsources data collection for studies implemented by scientific researchers towards educational or scientific advancements (Bonney et al., 2009b). In *community science*, collaboratively-led scientific investigation and exploration addresses community defined questions, allowing for engagement in the entirety of the scientific process. Unique in comparison to traditional citizen science driven by researchers or institutions, community science may or may not include partnerships with professional scientists, emphasizes the community's ownership of research and access to resulting data, and orients toward community goals and working together in scalable networks to encourage collaborative learning and civic engagement (Dosemagen and Gehrke, 2016). In community science, an institution does not conduct directed research but instead supports people in communities who are health and environment aware, able to indicate potential concerns, hotspots and/or trends and are able be both engaged in and driving engagement, monitoring and advocacy work.

Both citizen science and community science push for the democratization of science practices and the involvement of diverse communities of people, and these terms are not clearly defined in theory and practice. For example, the United States Environmental Protection Agency (US EPA) literature refers to the term 'citizen science' for both traditional citizen science led by scientists as well as community science, as defined here. Regardless of the terms used, it is our view that both institutionally-driven citizen science and community science are effective at supporting environmental protection, and in fact provide complementary approaches for addressing environmental issues.

Citizen science and community science offer opportunities for impact beyond science and can support progress in environmental protection in multiple complementary ways. Citizen science and community science can further progress in problems for which there is incomplete and contradictory knowledge and incompatible or conflicting perspectives or value positions; "wicked" problems that require the involvement of many stakeholders, like issues of environmental quality and conservation (Bonney et al., 2014; Ellwood et al., 2017). Citizen science and community science can help transition to new approaches to science and knowledge that emphasize dialogue, agency, capacity building, and collaborative learning (Dillon et al., 2016). Projects spanning a range of involvement provide opportunities for change at multiple scales. The degree to which members of the public are involved in science affects the scale and speed at which solutions are found and implemented; Danielson et al. (2010) found that environmental monitoring by scientists tended to result in policy action that was more long-term and at large scale, while environmental monitoring that involved the public resulted in local change much more quickly.

As citizen science and community science grow in participation and impact on science, local, state, tribal, and national governments are beginning to recognize the benefits and power of engaging with those collecting data about their environments. This emerging interest is beginning to enable the use of citizen science and community science in government action and promoting the use of citizen science and community science for action beyond research. However, the nature of these impacts is not well-defined, and the role of citizen science and community science organizations, participants, and governments is not well-established. In what ways can citizen science and community science support progress in environmental protection beyond research? What is the role of citizen science and community science in the changing landscape of environmental protection?

To answer these questions, we propose a spectrum of engagement in citizen science and community science and outline the ways in which engaged people and governments are pushing and moving toward more inclusive environmental protection. In a time in which the public and agencies need new methods to be stronger environmental and human health advocates and protectors, the following sections explore the many modes of citizen science and community science - the people using these approaches, the methods for citizen science and community science practice, and the role that partnerships play in increasing the impact of work across a spectrum of project outcomes.

Methods

This article comes out of a collaboration by the authors as co-editors of a report by the National

Advisory Council on Environmental Policy and Technology (NACEPT), a federal advisory council for the US EPA. In 2015, NACEPT was tasked with drafting recommendations to the US EPA Administration on the use of citizen science and community science for addressing three particular questions, 1) How can we sustain and improve current US EPA projects, 2) How can US EPA invest in citizen science approaches for the greatest gain, and 3) How can US EPA increase the impact of knowledge and data generated via citizen science (NACEPT, 2016). Twenty-eight members, representatives of tribal, state, and local government, academia, nonprofit and community-based organizations and industry, drafted a core set of thirteen recommendations, which can be found in the report *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA* (NACEPT, 2016). Author Parker is an ORISE Research Fellow hosted by US EPA and co-editor of the NACEPT report and author Dosemagen is a member of NACEPT and Executive Director of the Public Lab nonprofit.

The Council's process involved extensive research into citizen science and community science organizations and practices. The Council began with a set of presentations from citizen science and community science practitioners spanning tribal, federal, state, nonprofit, and academic work, and explored US EPA efforts related to citizen science and community science in air, water, environmental justice, and in the US EPA Regions. The Council also participated in webinars and discussions focused on current efforts in citizen science and community science, data management, and ethical, legal, and social implications. The Council broke into working groups to focus on strategic opportunities, community-driven citizen science (i.e. community science), and data quality and management; each working group conducted interviews of citizen science and community science practitioners and US EPA staff. The working groups developed white papers, after which the main ideas were synthesized and compiled into the final report (NACEPT, 2016).

Incorporating the feedback and contributions of NACEPT members and the wider citizen science and community science fields, the council identified a spectrum of projects, widely varying outcomes and using methods and techniques indicative of projects designed for the ability of people to participate – ranging from a pastor in El Paso, Texas using local knowledge of burials to indicate a cancer cluster to a bucket brigade in Tonawanda, NY providing the first set of data for US EPA enforcement actions. These case studies provide examples for how citizen science and community science can contribute to a wide range of outcomes in environmental protection. Some of these examples relate to US EPA, but most do not - indicating that environmental protection is broadening to include a more diverse range of organizations and participants working towards a range of outcomes.

Trajectory of US EPA citizen science and the broader field

Community science projects are often a response to the perception that local, state, tribal, and federal governments are not responsive to community concerns, and community groups are often frustrated at the inability or unwillingness of federal, tribal, state, and local agencies to assess their data and respond with action. As a result, community science programs and participants are often defined by antagonism towards institutions and governments. However, gradually accumulating examples demonstrate that a combination of approaches — using both traditional research and regulatory roles and innovative efforts by citizen science and community groups — can be very successful in addressing complex issues at multiple levels and promoting positive interactions between individuals, communities, and government.

Since its creation, many have considered the US EPA to be the most powerful voice for environmental protection in the United States. The environmental movement of the 1960s contested widespread environmental pollution and issues such as Dichlorodiphenyltrichloroethane (DDT) and waste dumping; these issues motivated the creation of the US EPA by the Nixon Administration in 1970. The US EPA is tasked with protecting human health and the environment, and was developed to merge environmental research, monitoring, enforcement and standard setting and set up to tackle increasingly evident environmental pollution (EPA, 2016). However, the ability for the US EPA to accomplish environmental protection on its own is often questioned. Since the 1970s, green groups (e.g. Greenpeace and the Natural Resources Defense Council) and grassroots groups (e.g. those organized around environmental justice and health issues) have drawn attention to and called on US EPA for stronger responses to pressing environmental concerns. Critiquing both US EPA and the environmental movement as a whole, Shellenberger and Nordhaus (2004) noted that the complexity of the environmental issues and systems — such as climate change — were not being adequately addressed by the modern framing of environmental advocacy and protection.

In the last twenty years, a transformation has begun outside of traditional institutions and is changing the environmental movement and the work of government agencies. This transformation is having a direct and lasting influence on how environmental advocacy and protection is accomplished. Environmental protection is broadening; individuals and communities are more motivated to engage, and agencies are moving toward more inclusive visions of government. The increasing prevalence of open data, civic media, citizen science and community science point to one central conclusion - in addressing our increasingly complex environments, the power lies in the participation of many.

There is increasing evidence that US EPA recognizes that responsiveness to citizen science and community science needs additional attention. Advisory councils have taken on these issues, often under the direction or with the support of US EPA. In 2012, the National Advisory Council for Environmental Policy and Technology (NACEPT) recommended that US EPA Administrator Lisa Jackson address environmental justice issues and support vulnerable populations in collecting data on environmental health concerns. In 2017, the National Environmental Justice Advisory Council (NEJAC) provided US EPA with recommendations that center on the important role of building trust between government staff and communities in order to support community monitoring. In 2015, the US EPA charged the National Advisory Council for Environmental Policy and Technology with developing advice and recommendations on how to integrate citizen science into the work of US EPA. This work culminated in two reports to US EPA advocating for proactive integration of citizen science and community science into all aspects of US EPA work: *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA* and *Information to Action: Strengthening EPA Citizen Science Partnerships for Environmental Protection* (NACEPT, 2016; NACEPT, 2018).

Within the US EPA itself a number of events have communicated increasing legitimacy of citizen science and community science in the federal space. In July 2015, US EPA held a Community Air Monitoring Training, inviting 30 community members representing local organizations from across the United States to discuss best practices for using Next Generation Air Monitoring technology. In June 2016, US EPA's New England Region hosted an Open Space meeting for US EPA and state employees, nongovernmental organizations, and community groups to discuss opportunities and barriers for environmental citizen science and community science.

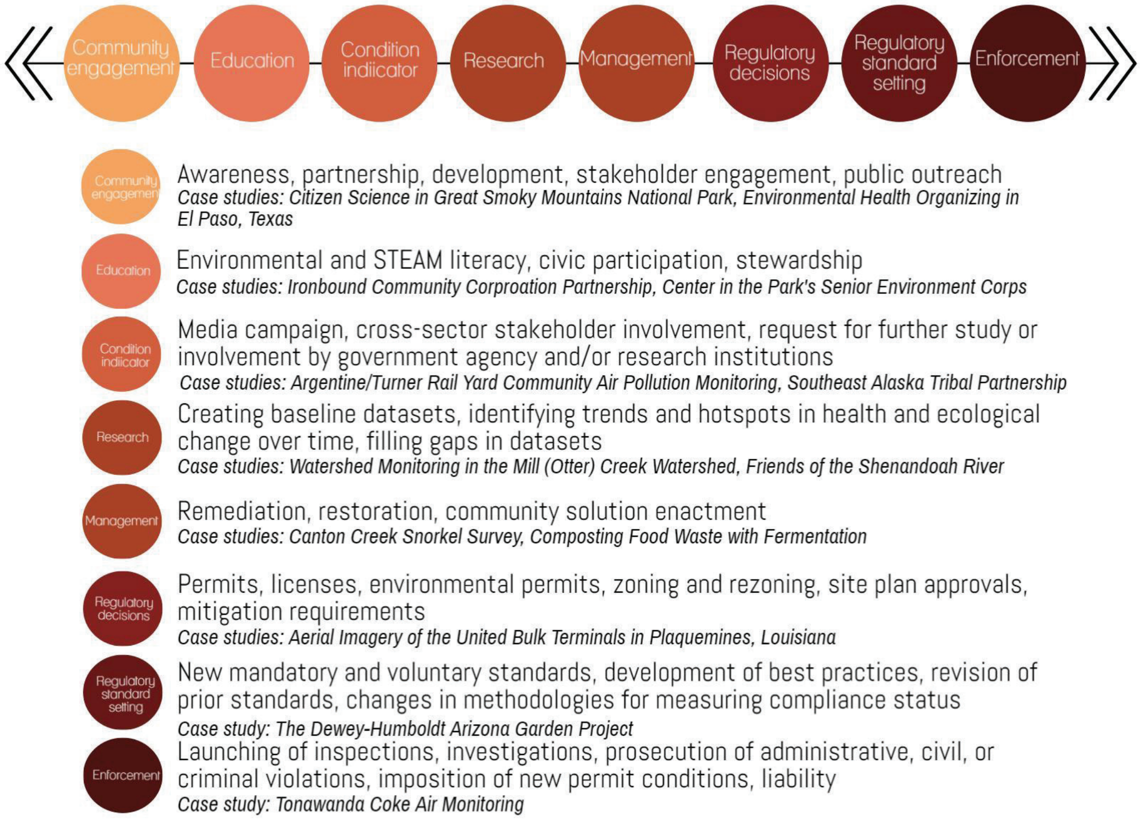
Historically, US EPA support for citizen science and community science was focused mainly on volunteer water monitoring programs with funding and organizational support from US EPA's Office of Water. More recently, programs throughout US EPA's programs and regions communicate an increased interest and legitimacy of public involvement in US EPA research and policy. This includes projects driven by US EPA and its scientists as well as collaborative partnerships with community organizations. In New Jersey, US EPA scientists worked with the Ironbound Community Corporation to better understand air quality in Newark, including sensor technology and study design support. In California, US EPA participates in the Identifying Violations Affecting Neighborhoods (IVAN) network and is working to support the network in developing performance measures. In the Northwest region, US EPA works extensively with community groups to use US EPA tools such as the Environmental Justice Screening and Mapping Tool (EJSCREEN), the Community-Focused Exposure and Risk Screening Tool

(C-FERST), the Community-Line Source Model (C-LINE), and EnviroAtlas.

Moreover, citizen science is gaining popularity and acceptance across the United States federal government. In September 2015, US President Barack Obama's Science Advisor John Holdren (2015) issued a policy memo encouraging federal agencies to use citizen science and crowdsourcing approaches. The memo outlines principles for the use of these approaches, including the "fitness for use" of citizen science data, openness, and public participation. In addition, Congress passed legislation – signed by President Obama in January 2016 – encouraging the use of citizen science by federal agencies. Although these federal policies initially focus on institutional citizen science, the gradual movement towards embracing these principles – especially a shift in agency culture towards the acceptance of citizen science data – will open opportunities for both citizen science and community science.

Spectrum of Engagement

A primary motivation for many involved in citizen science and community science is the potential for change. Modified from the Wilson Center report *Clearing the Path: Citizen Science and Public Decision Making in the United States* (McElfish et al., 2016), the National Advisory Council for Policy and Technology adopted a spectrum of engagement to describe the range of ways that citizen science and community science data can be used to impact environmental protection. This spectrum, described in *Environmental Protection Belongs to the Public: A Vision for Citizen Science at EPA*, demonstrates the potential for citizen science and community science to transform not only environmental research, but all aspects of environmental protection from civic engagement to environmental regulations. Citizen science and community science support research and can also provide a holistic approach for engaging with complex issues that cannot be solved through



Awareness, partnership, development, stakeholder engagement, public outreach
Case studies: Citizen Science in Great Smoky Mountains National Park, Environmental Health Organizing in El Paso, Texas

Environmental and STEAM literacy, civic participation, stewardship
Case studies: Ironbound Community Corproation Partnership, Center in the Park's Senior Environment Corps

Media campaign, cross-sector stakeholder involvement, request for further study or involvement by government agency and/or research institutions
Case studies: Argentine/Turner Rail Yard Community Air Pollution Monitoring, Southeast Alaska Tribal Partnership

Creating baseline datasets, identifying trends and hotspots in health and ecological change over time, filling gaps in datasets
Case studies: Watershed Monitoring in the Mill (Otter) Creek Watershed, Friends of the Shenandoah River

Remediation, restoration, community solution enactment
Case studies: Canton Creek Snorkel Survey, Composting Food Waste with Fermentation

Permits, licenses, environmental permits, zoning and rezoning, site plan approvals, mitigation requirements
Case studies: Aerial Imagery of the United Bulk Terminals in Plaquemines, Louisiana

New mandatory and voluntary standards, development of best practices, revision of prior standards, changes in methodologies for measuring compliance status
Case study: The Dewey-Humboldt Arizona Garden Project

Launching of inspections, investigations, prosecution of administrative, civil, or criminal violations, imposition of new permit conditions, liability
Case study: Tonawanda Coke Air Monitoring

Figure 1. The spectrum of engagement describes the range of ways that citizen science and community science data can be used to impact environmental protection. Case studies for each category of citizen science data use demonstrate how citizen science and community science can support all aspects of environmental protection from civic engagement to environmental regulations.

science alone. More and more, people are finding opportunities to engage in scientific processes towards actionable goals.

Case Studies

Community Engagement

At their cores, citizen science and community science are tools for engaging all parts of society in complex environmental problems, mobilizing diverse individuals for change, and building populations equipped to advocate for their own health and environments.

In El Paso, Texas, Father Pablo Matta of Westway's Imaculado Corazón de María Catholic Church noticed a pattern in increasing deaths from cancer, and voiced his concerns to the local community. His initial advocacy led to members and organizers of the Westway community in Texas to use community-based participatory research methods to document evidence of a cancer cluster (Staudt et al., 2015).

Education

Citizen science and community science are valuable tools for informal and formal education, especially environmental and science literacy. Many citizen science and community science projects include education as a key goal (Bonney et al., 2009a). In particular, many community science projects build community education and capacity, which in turn can lead to broader impacts over time.

In the Ironbound community of Newark, New Jersey, US EPA partnered with community organizations – including the Ironbound Community Corporation – to conduct local air monitoring. US EPA designed air monitors, including protocols for where the instruments should be located and how to maintain and operate them, and provided resources for data management and quality assurance. Community members collected data on nitrous oxide and fine particulate matter and learned to understand local environmental conditions, which allowed them to identify neighborhood trends and make local decisions. This project facilitated education in the community and build community capacity for environmental monitoring (EPA, 2015; NACEPT, 2016).

Condition Indicator

Citizen science and community science data can play an important role as indicators of environmental conditions, which can raise public awareness of environmental concerns and motivate further action. Projects that indicate the environmental conditions can include or motivate a media campaign, cross-sector stakeholder involvement, a request for further study or involvement by a government agency (such as US EPA) or a research institution.

In Philadelphia, the Center in the Park's Senior Environment Corps supports older adults in playing active, visible roles in education and advocacy; for example, volunteers were able to identify high incidence of *E. coli* in Monoshone Creek, which motivated response from the Philadelphia Water Department, the Pennsylvania Department of Environmental Protection, and the US EPA and led ultimately to an emergency contract from the Philadelphia Water Department (Siegal, 2016; NACEPT, 2016).

In Kansas City, Kansas, a community air monitoring project looked at emissions from diesel switch yard locomotives and their effect on community health. The project documented excessive levels of elemental carbon (EC) in local neighborhoods with the potential for extreme cardiovascular and respiratory health risks. Local coverage of the results motivated dialog between a local Good Neighbor Committee and BNSF Railway about strategies for emissions reductions (Diesel Health Project, 2015; NACEPT, 2016).

In Southeast Alaska, the Southeast Alaska Tribal Ocean Research (SEATOR) program supports research on the impacts of climate change on the marine environments conducted by tribes, especially in relation to paralytic shellfish poisoning from harmful algal blooms. The program fills a gap in Alaska state agency monitoring of paralytic shellfish poisoning by monitoring subsistence and recreational shellfish. Data are provided to NOAA's SoundToxin database and the Phytoplankton Monitoring Network and provide for forecasting and early warning (SEATOR, 2015; NACEPT, 2016).

Research

Within the field of citizen science, there is a rich tradition of citizen science approaches for research; however, this progress has happened largely in research conducted by academic and non-governmental organizations. Recently, local, state, tribal, and national governments are recognizing the ability for citizen science and community science to support science normally conducted completely within institutional walls. Citizen science and community science have a great deal of possible uses for expanding baseline knowledge and supporting research and management decisions (Converse et al., 2016). Projects with a research focus can create baseline datasets, identify trends and hotspots in health and ecological change over time, and fill research gaps.

In the Mill/Otter Creek watershed in the Delaware Estuary Coastal Zone, the Friends of the Silver Lake Nature Center tests sites in the watershed for pH, dissolved oxygen, nutrients such as phosphates and nitrates, identifies aquatic organisms, and maps stormwater drainage outfalls; the data are shared with Delaware Riverkeeper, Pennsylvania Department of Environmental Protection, Pennsylvania Fish and Boat Commission, health departments, and Stroud Water Research Center (NACEPT, 2016).

The Friends of the Shenandoah River operate a water quality analysis laboratory with Virginia Department of Environmental Quality Level III accreditation, and operate a network of volunteer water quality monitors that collect data on nutrients, water chemistry, water physical characteristics, bacteria, and benthic factors. These data are used by the Virginia Department of Environmental Quality for reports to US EPA, listing impaired streams, delisting non impaired stream segments, and inform the community about exposure and risk at recreational areas and in drinking water (NACEPT, 2016).

Management Decisions

Citizen science and community science projects can support remediation, restoration, and enactment of community solutions to environmental problems. The Canton Creek Snorkel Survey monitors the abundance and distribution of salmonids in the Canton Creek Watershed and expects to provide long-term baseline data, and this effort promotes the management and restoration of this watershed. In the Washington DC region, a grassroots environmental group implements a fermentation composting method (Bokashi composting) for church functions and church members at three Episcopal Korean churches in Maryland and Virginia (NACEPT, 2016).

Regulatory Decisions

In recent years, citizen science and community science are beginning to complement traditional regulatory and enforcement processes. While uncommon, there are a number of examples of citizen science and community science informing regulatory and enforcement action.

Communities surrounding the United Bulk Terminals in Plaquemines, Louisiana were concerned about ongoing environmental issues like coal dust. The Clean Gulf Commerce Coalition demonstrated systematic problems from faulty equipment through aerial imagery, leading to a consent decree and fines from the Louisiana Department of Environmental Quality and a lawsuit resulting in stricter pollution prevention terms, additional fines for wetland restoration, and corrections to facilities and operations (U.S. District Court for the Eastern District of Louisiana, 2015; NACEPT, 2016).

Regulatory Standard Setting

Communities surrounding the Iron King Mine and Humboldt Smelter Superfund Sites were concerned about arsenic and lead in vegetables from their home gardens. Through the project Gardenroots, the communities and a University of Arizona researcher worked together to investigate arsenic exposure and risk. The study revealed that local public water exceeded the arsenic drinking water standard, resulting in a notice of violation to the municipal water supplier (Ramirez-Andreotta, 2014; NACEPT, 2016).

Colorado River Watch brings together 140 groups monitoring 650 locations for water quality, including chemical, macroinvertebrate, and physical habitat assessment. Data are used for many purposes, including standard development and setting, use assessment, impaired stream listing/delisting, development and monitoring of total maximum daily loads, and nonpoint source project monitoring. These data are more comprehensive, both temporally and spatially, than those from any other data provider that can be used in regulatory standard setting hearings (NACEPT, 2016).

Enforcement

In Tonawanda, New York, community members were concerned about the health impacts of local industry. They collected local air samples that indicated extremely high levels of benzene. A year-long follow-up study by the New York State Department of Environmental Conservation confirmed this result. This work resulted in US EPA enforcement action, a criminal trial, the conviction of the environmental control manager for Tonawanda Coke, and ultimately, 68% and 86% reductions of benzene as measured by local air monitors (NACEPT, 2016; James-Creedon, 2016).

Conclusion

The case studies presented here provide models for how citizen science and community science can support a range of outcomes, from community engagement and education to regulations and enforcement. Many times, the motivation and energy behind those outcomes are a result of individuals' and communities' motivation for change. To support the full spectrum of engagement in environmental protection, institutions should support early involvement by communities – including problem identification and goal setting by the people asking the questions – at both a partnership and policy level. Institutions should consider how they can bolster the capacity of community science projects through focusing funding and technical support resources towards project goals and community skill building. Opportunities for true co-design should be identified and implemented with community members. Policies that create clear standards can bridge current gaps between citizen science and community science and institutions (Ottinger, 2009), which would support a range of citizen science and community science projects and allow for more action across the spectrum of engagement.

As environmentalism and environmental protection change, new approaches to collaboration are essential to tackle complex problems. Citizen science and community science invite the participation of everyone into work traditionally reserved for professionals. Similarly, environmental protection needs the action of a diverse crowd that includes activists, researchers, and enthusiasts in addition to the work of government agencies. Research is just one way that citizen scientists and activists can participate in solving environmental issues; citizen science and community science can support environmental protection through a full spectrum of activities, including supporting civic engagement, education, condition indicating, management, regulations, regulatory standard setting, and enforcement. The spectrum of engagement outlines a variety of ways that citizen science and community science can complement traditional work in environmental protection. Citizen science and community science provide ways to bring together diverse groups towards common goals, and these approaches to environmental work are changing how communities engage with their own environment and health and the way that government and institutions interact with the public.

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Modes and Existences in Citizen Science:
Thoughts from Earthquake Country

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Abstract

In the Bay Area of San Francisco, the earthquake contours are not easy to define: seismology is still a relatively recent science, and controversies around methods to evaluate the earthquake risk are constant. In this context, the invitation to think about the modes of citizen science is an opportunity to reflect on the modality of hybridized scientific practices as well as the process by which the plurality and complexity of the earthquake characteristics can be articulated, and sometime reconciled.

Looking at different existences of the earthquake risk, the paper investigates different assemblages that question the clear-cut distinction between citizen science and science. I'll situate the question of the mode of citizen science within the larger framework of interdisciplinarity knowledge infrastructures and the work on 'mode of existence' initiated by Bruno Latour and Isabelle Stengers (2009).

Expanding our understanding with regard to how CS is performed opens the possibility of reconsidering the specific types of assemblages and infrastructures from which these modes emerge and on their distinct trajectories. It is also an invitation to make visible the integration processes, the communities, and the imaginations that "make" science.

Keywords: existence, earthquake, risk, knowledge, infrastructure, data

Introduction

On March 11, 2011, the Tōhoku earthquake and tsunami (also referred as the Great East Japan Earthquake) partially destroyed the Fukushima Daiichi Nuclear Power Plant, caused the death of 15,884 people, led to the evacuation of 300,000 others, and triggered a nuclear accident whose causes and long-term consequences are still under investigation (Ahn et al., 2015; Guarnieri and Travadel, 2018; Hasegawa, 2013; Kalmbach, 2015). The series of events constituting the earthquake, the tsunami and the ensuing nuclear disaster as well as its scale and amplitude were breathtaking and took the international community by surprise.

In Berkeley, California, the emotions aroused by the catastrophe and the threat of a nuclear disaster kept residents under alert. Like millions of others, I was glued to my computer, watching CNN live, trying to make sense of the information I had, and speculating on what was not yet known. Everywhere—in supermarkets, on playgrounds, at work—discussions swirled around the disaster, the sorrow, the pain, and the risk. On April 20, 2011, an interdisciplinary group of UC Berkeley faculty members gathered in an open discussion entitled "Coping with the Crisis: Implications for Japan's Future".[1] That evening, the panelists openly and genuinely shared their thoughts and their knowledge about what had happened, what it meant for the affected communities but also, for rest of us. The room was full, the faces were grave, and the discussion kept going for long hours, as people tried to sort out the information coming from divergent sources: the Japanese government, the news agencies, the citizen science network, the scientists (Shineha and Tanaka, 2017).

In the room, residents, other faculty members, and concerned citizens were wondering whom to trust and where to go from there.[2] This discussion was the first of many organized at UC Berkeley, stirred by a group of dedicated and concerned scholars[3] willing to use their knowledge and energy to limit the spectrum of the catastrophe unfolding under our eyes, informing the public and the policy makers. Relying on an international network of experts, citizen scientists, academics, friends, and family members, they translated and discussed information, weighing contributions from those who could take part in this large enterprise of interdisciplinary sense-making. As a graduate student working on risk in the San Francisco Bay Area, I was invited to participate in three of these workshops (Ahn et al., 2017; Akera, 2007; Amir, 2018), where scholars tried to find a common language to describe the complexity of the disaster that had been a deep emotional and intellectual shock. Building on what French philosopher Emilie Hache has described as a too-often disregarded competence of the Moderns—i.e., the capacity to use our emotional response to disaster as the trigger for constructive action to "collectively put words on a collective fear and draw energy to act" (quoted in Vincent, 2017), these scholars were joining forces to think through the multiple, intricate, complicated, and often contradictory dimensions of disasters at the scale of the Fukushima Daiichi event.

From modes of citizen science to disaster modes of existence.

The invitation to reflect on the modes of citizen science is an opportunity to reflect on the modality of hybridized scientific practices focusing on the modes of existence of the earthquake, such as I was able to experience them during my field work. In this paper, I'll situate the question of the mode of citizen science within the larger framework of interdisciplinarity knowledge infrastructures (Edwards et al., 2013; Fortun and Fortun, 2015; Lin et al., 2016; Pollock and Williams, 2010; Ribes and Lee, 2010) and work on "mode of existence" initiated by Bruno Latour and Isabelle Stengers (Latour, 2011; Stengers and Latour, 2009), and expanded by a large collaborative and exploratory project of co-construction "AiME project -An Inquiry into Modes of Existence" (Latour, 2013).[4]

In recent years, researchers have pointed out that what is often described as citizen science (CS) encompasses distinctive modes, often understood as differentiated sets of practices, purposes, and objectives (Eitzel et al., 2017. Kullenberg & Kasperowski, 2016; Selin et al., 2016; Traweek, 2013) Yet others, working on the role of data (and data science practices), have contributed to a better understanding of the processes by which heterogeneous data get integrated allowing for the emergence of interdisciplinary practices (Boix Mansilla et al., 2016; Borgman, 2013; Jirotka et al., 2013; Leonelli et al., 2017). This proliferation of digital tools, objects and practices has led to what Marres has described as a "redistribution of research" and a "redistribution of methods" which recognizes the contributions of various agents, "researchers, research subjects, funders, providers of research materials, infrastructure builders, interested amateurs, and so on," (Marres, 2012:140) and the modalities of enactments that are often hard to pin down.[5] Researchers have also noted that these data practices and modes of producing knowledge emerge from organizational settings, standards, and norms that define collaboration and interdisciplinarity in scientific arenas (Aronova, 2017; Landström, Whatmore, and Lane, 2011; Riesch and Nowotny, 2017) as well as by the virtues and political consequences attributed to what has often been thought of as – and criticized for being - a one-dimensional relationships between experts and non-experts (Allen, 2011; Kimura and Kinchy, 2016; Lidskog, 2008; Lynch, 2014; Wynne, 1996).

Following what has been referred to as the ontological turn of in Science and Technology Studies (Law and Lien, 2013; Lynch, 2013; Mol, 2013), researchers have acknowledged that there may be different ways to understand ontological questions that are "in actuality decided through specific, historical, cultural, technological, scientific interventions" (Marres, 2013: 423). Expanding our understanding with regard to how CS is performed, opens the possibility of reflecting on the specific types of assemblages from which these modes emerge and on their specific existences. It is also an invitation to reflect on the integration processes (Akera and Mohsin, 2016; Gerson, 2012; Star and Griesemer, 1989), the communities (Knorr-Cetina, 1999), and the imaginations (Jasanoff and Kim, 2015) that "make" science. Questioning the modality of citizen science therefore requires thinking about the ways in which science is conducted: the modi operandi (Whatmore, 2009) according to which the order of things is determined. It also requires a description of how the work of sense-making and knowledge-building is accomplished, recognizing the co-existence of multiple methods, epistemologies but also existences of the object under investigation. Doing so, I would like to argue for a displacement from the question of the mode of citizen science to the possibly larger question of the mode of existence of the objects of citizen science. I hope that framing the contours of these modes of existence will allow the emergence of coherent pragmatic and epistemic assemblages, precise and labeled modalities of existence, that will help, in return, clarify the need of extending the articulations of modes of citizen science.

As the discussions in the aftermath of the Tōhoku earthquake and tsunami and Fukushima Daiichi Nuclear disaster made explicit, studying disasters with the tools of academic knowledge is a humbling experience. Not a single discipline or method can describe or explain the entire chain of reactions leading to a catastrophe of the scope of the 2011 events (Fortun et al., 2016; Mazel-Cabasse, 2017, 2018). Rather, the catastrophic event can be approached as an association of distinctive modalities, or modes of knowing, that crosses traditional division of academic disciplines and methods: "[D]isasters come into existence in both the material and the social world and perhaps, in some hybrid space between them" (Oliver-Smith and Hoffman, 1999: 24). What seems coherent and valid from the perspective of the event is sometimes hard to articulate and prone to debate from the perspective of well-defined academic disciplines.

To account for this complexity, anthropologists have argued that disasters "are both socially constructed and experienced differently by different groups and individuals, generating multiple interpretations of an event/process. A single disaster can fragment into different and conflicting sets of circumstances and interpretations according to the experience and identity of those affected" (Oliver-Smith, 1999: 26). In the second half of the 20th century, the French philosopher Etienne Souriau (1892-1979) had explored the possibility of this *existential pluralism* and proposed to think about existences as multiples and co-existing modes, allowing us to describe associations or phenomena that are situated without being ethno- or geo-centered.[6] Before him, and focusing this time on earthquakes, the American philosopher William James writing about his experience of the 1906 earthquake and fire that partially destroyed San Francisco, was aware of the articulations that define - for scientists, residents, and himself - the multiple but simultaneous existences of the earthquake. In a piece published under the title *"On Some Mental Effects of the Earthquake"* he reflected on the definition of the earthquake: "For '*science*,' when the tensions in the earth's crust reach the breaking point, and strata fall into an altered equilibrium, earthquake is simply the collective name of all the cracks and shakings and disturbances that happen. They are the earthquakes. But for me the earthquake was the cause of the disturbances, and the perception of it as a living agent was irresistible" (James, 1906: 1216-1217).

In the next sections, I will look at the constant re-organization of specific assemblages that have been necessary to grasp the complexity of the modes of existence of the earthquake in the Bay

Area of San Francisco. Using William James's own words as a red thread, I will show how each of these specific configurations is necessary to bring the earthquake it's full existence.

The mode of existence of the earthquake in the Bay Area

I will first explore what happens when the "tensions in the earth's crust reach the breaking point" and look at the history of Seismology as a scientific discipline as an important moment of definition of the earthquake as an object of science. Next, I will look at the risk of earthquake or what James has described as the "altered equilibrium": in this case, I'll use the hazard map, which requires the mobilization of various tool sets to both solidify and transport what has been previously defined as the earthquake. Finally, I'll investigate the possibility for the earthquake to be considered as a "living agent," a phenomenon in the Souriau's sense, that needs to be experienced to be known.

Mode of existence 1. When the "tensions in the earth's crust reach the breaking point"

When James write about his experience of the 1906 earthquake, Seismology is a very different discipline than it is today. Some of the earliest-known scientific comments regarding earthquakes occurred in the mid-1600s, but most historiography on seismology starts soon after the Lisbon Earthquake in 1755 and rely on the detailed descriptions of "Earthquake Observers" (Coen, 2013, but also Quenet, 2005). For centuries, discoveries have been driven by observations of large earthquakes: the solidification of the discipline can be described as the co-production (Jasanoff, 1999, 2004) of the tools and methods needed to comprehend the trigger mechanisms and the risk it represents. In Northern California, the first earthquake known as the "Big One" happened in 1868 in the still very rural State; despite little damages the event prompted the installation of the first seismometers at the University of California, Berkeley. When instrumentation was scarce and theory still in formation, science continue to rely on the descriptions of trained observers who were not always scientists or experts. No detail was too small and no nuance in the experience of a felt earthquake too trivial to be left undocumented. To define earthquakes, seismologists and local earthquakes observers used their own perceptions of the event ("How did the earthquake feel?") as well as their sense of observation ("What did it produce?") (Coen, 2013).

The field went through a first important transformation after the 1906 earthquake, when data collection became more systematic and organized: the Lawson Commission's report was the first full-scale attempt to comprehensively document an earthquake. Rupturing 296 miles of the San Andreas fault, the magnitude 7.9 earthquake "afforded an exceptional opportunity for adding to our knowledge of earthquakes" noted geologist Andrew Lawson, head of the commission and chair of the Department of Geology at the University of California, Berkeley (in Lewis, 2008). To accomplished this prodigious task, he dispatched teams of observers on foot and horseback to explore the fault, from Humboldt County in Northern California to the Coachella Valley, south of Los Angeles. By 1908, he had mapped the entire San Andreas Fault and went on completing a report which included the elastic–rebound theory, another important step in understanding of the earthquake mechanism.[7]

From that moment, interest for earthquake as phenomena kept growing in California. In the first part of the twentieth century, Harry O. Wood, Franck Neumann and Charles Richter, defined intensity and magnitude scales conceived as interpretive frameworks for earthquakes: translation tools that were aimed to describe particular earthquakes into words and situate them on a scale. In 1931, Harry O. Wood, who had been working for decades with eyewitness earthquake observation reports (the "felt reports"), published the "Modified Mercalli Scales" with Franck Neumann. This new scale was designed to make reporting easier by defining the earthquake with degrees and thresholds, thus eliminating ambiguities, but also to "insert explicit statement[s] about the mental states conducive to certain reported effects" (Coen, 2013: 258).[8] At the time of publication of this scale, Seismology was still very much considered an imperfect science. Wood and Neumann noted that, "though the importance of the factor of acceleration is recognized, we have as yet no satisfactory definition of intensity, no formula expressing earthquake violence in term of ground movement" (Wood and Neumann as cited in Coen, 2013: 259). For this reason, Wood encouraged the young Charles Richter to focus on this particular problem: creating a mechanical equivalent of intensity: the Richter's magnitude scale, which measures the strength of earthquake was introduced in 1935.[9] What made this scientific breakthrough possible is the translation of the earthquake experience - how it felt, where it had occurred, and what damage it caused – to a fact that science could take for granted.

In the last decades of the twentieth-century, scales describing the earthquake as perceived by human have continued to be very successful in Seismology. In the US,[10] the "Did You Feel It?" program (DYFI) administered by the US Geological Survey (USGS) collects real-time information and measurements from earthquake witnesses. "The idea of the DYFI program is that citizens use an Internet Web site[11] to report their experiences and observations for any earthquakes that they have felt (or not felt) by answering a simple multiple-choice questionnaire." (Atkinson and Wald, 2007) Respondents' answers are used as a diagnostic of Modified Mercalli Intensity at the observers' locations and are later visualized into a map. With the help of the "distance versus intensity" calculation, these personal testimonies are translated into a Community Internet Intensity Map (CIIM). The CIIM records perceptions of earthquake, organizes them, and helps scientists to visualize experiences derived from collective perceptions, and observations of the event. Still called "felt maps," these community-generated maps are found to be "surprisingly" (Atkinson and Wald, 2007: 362) valuable for the scientific community, "especially when considering the limited efforts required for implementation" (Bossu et al., 2008: 224).

The qualitative and quantitative approaches of the earthquake have never ceased to co-exist, generating and translating different forms of socio-technical assemblages that pursue the same objective: getting a more precise representation of the earthquake signals and a better understanding of the mechanism that trigger tectonic plates movement. During that period, the development of seismology has brought together a number of disciplines that have joined forces to get into the details of the unfolding nature of earthquakes. In 1998, the National Science Foundation (NSF) established the collaborative Network for Earthquake Engineering Simulation (NEES) with 14 research centers that share a centralized data repository and earthquake simulation software.[12] To guarantee progress, this research consortium relies heavily on networks of seismographs, GPS devices and broader range of geophysical monitoring devices, which have been used continuously since the 1960s. Today's felts reports, witeness testimonies and data collections from devices combined with the portability of mobiles application continue to be a key element to the identification and decription of seimologcal events (Bossu et al., 2015). Whether interpreting their own observations or relying on the traces of a seismograph,[13] seismologists and observers make connections in order to establish relations between experience and science. Through this heterogeneous dataset, they've learned how to "read" important signals, to organize sensations, observations and recollections into the coherent form of a particular seismic event (November et al., 2009).

Mode of existence 2. Scenario and map: navigating the "altered equilibrium"

Until today, these programs continue to gather an impressive amount of data—shared across laboratories and universities. Focusing on the infrastructure for data collection, the first mode of existence described the materialization of the earthquake as an object of scientific enquiry. Progressively emerging as objects of science starting from the exploration of its traces to the collection and synthetization of digitalized data, the "tensions in the earth's crust reach the breaking point" are still being discovered through a system of "circulating references" (Latour, 2000). In this section, we'll see how, from the contested and unstable definition of the earthquake, emerges an elusive but performative existence of the risk. To do so will look at the USGS Seismic Hazard Map which is at the same time a document with transformative capacities (Asdal, 2015) and a navigation system (November et al., 2010) which opens a window of continuity between the realm of everyday and the realm of possible events. The production Seismic Hazard Map brings together a long chain of facts and figures, tools, funding agencies, political will, and organizational cooperation that illustrates the familiar path of major scientific research (Lynch, 2012) and make the traces of the earthquake visible and transportable.

It is largely acknowledged that "another large earthquake in the San Francisco Bay Area is inevitable and imminent in geologic time" (Stark and Freedman, 2009: 126). As the popular saying goes, "the question is not *if*, the question is *when*." But despite recurring - and alarming - predictions, large disasters are rare. Not totally forgotten but not totally present, their existences seem incomplete or partial - that is, until they become destructive and their multidimensionality breathtaking. As we've seen, earthquakes, before they happen, are never completely predefined; instead, they have changing characteristics resulting from their complex trajectory: from the moment of recognition, to being identified as a quantifiable risk. To narrow down the characteristics of the " altered equilibrium," scientists and experts have developed earthquake scenarios which rely on an assemblage that some have described as a "mixture of geological maps, rules of thumb, expert opinion, physical models, stochastic models, numerical simulations, as well as geodetic, seismic, and paleo seismic data" (Stark and Freedman, 2009: 116).

Earthquake-risk scenarios focus mainly on calculations, whether they concern the probability of a fault rupture or the insured or uninsured costs incurred for a particular rupture in a given place. They investigate the interactions of tectonic-plate movement (Modified Mercalli Intensity, magnitude, liquefaction) and their consequences (fire-related damage, floods, landslides); the potentially aggravating factors (wind conditions and other adverse meteorological conditions) and their effects on buildings (retrofitted, not retrofitted, soft-story, unreinforced, masonry), public facilities (schools, hospitals, state and federal buildings), infrastructure (water, sewer, gas, transportation, bridges, piers, tunnels), population (prepared or not, injured, dead, displaced, or traumatized), and economic situation (sales, taxes, revenue, insurance, mortgage defaults), to name just a few. They also analyze and study the consequences of past events: the 1906 Earthquake and the subsequent San Francisco Fire (Perkins et al., 2006; Tobriner, 2006), the Loma Prieta Earthquake (Bourque and Russell, 1994; Nigg and Mileti, 1998), the Oakland Fire (FEMA, 1991b; Hoffman, 1998; Schiewe, 2011), and the Northridge Earthquake (Bolin and Stanford, 1998; Comfort, 1994; Tierney,

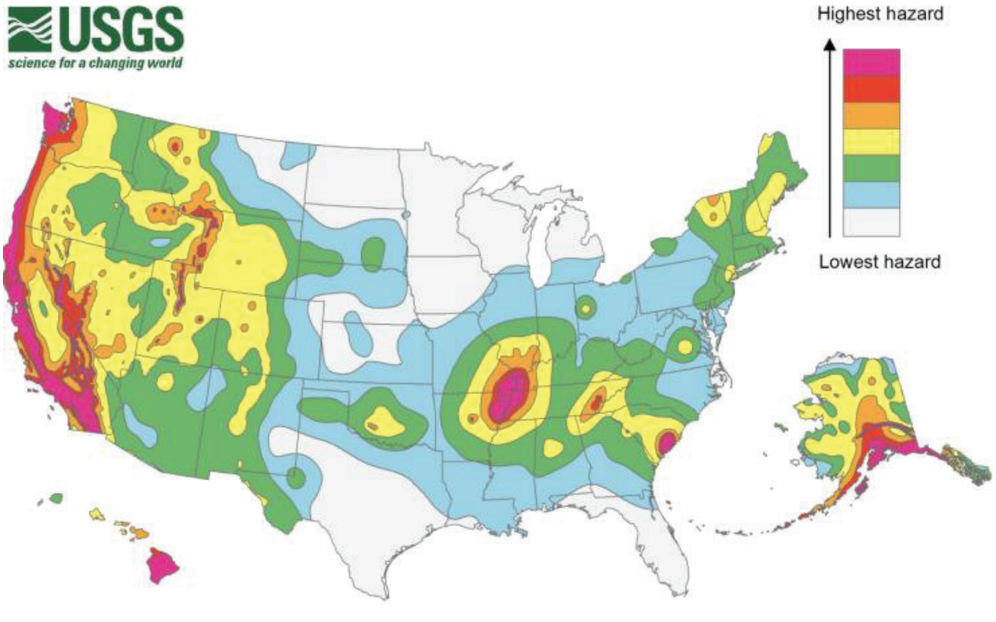

Figure 1. Simplified 2014 Hazard Map (PGA, 2% in 50 years). Source: USGS.

1995), making critical assessments of disaster responses at the time.

Interdisciplinary working groups are the always-moving forms of organizations producing earthquake data for broader earthquake communities. They are responsible for the production of reports, fact sheets, and maps. The work of data compilation needed to evaluate earthquake risks is colossal: during the last few decades, each Working Group has gathered together about 100 scientists (USGS, 1999, 2003). In California, the USGS and its local branch, the California Geological Survey (CGS); FEMA and its local branch, Cal-EMA; the Seismological Laboratory at the University of California, Berkeley; and the Lawrence Livermore National Laboratory (LLNL) were among the first to produce fact sheets and earthquake probabilities. The following diagram introduces the agencies present in 2008 and the process of data validation of the National *Earthquake* Hazards Reduction *Program* (NEHRP) program.[14]

As the diagram shows, individual California scientists, engineers, and policy makers, coming from a wide number of academic institutions, private-sector and government agencies, together with the Working Group on California Earthquake Probabilities (WGCEP), the California Geological Survey (CGS), and the Southern California Earthquake Center (SCEC), work together to determine the most accurate methodology for developing an earthquake forecasting model. Together, they contribute to the creation of the establishment of the USGS National Seismic Hazard Map, which continues to be updated through the years. These working groups rely on public funding, which for several decades has provided grants and cooperative financial agreements to support creation and analysis of their data.

Despite this impressive amount of work, experts and scientists have noted that large earthquakes more often happened where they are not expected: "We think we understand where all the faults are, so we know where they're going to occur, but both the Northridge and Loma Prieta earthquakes occurred on unknown faults. That was a surprise to me professionally" recalled an earthquake expert and Bay Area resident. Corroborating this statement, statisticians have determined that the earthquake "probability estimate (is) shaky, as is the uncertainty estimate." They also noted that the characteristics earthquake model (which include the elastic rebound paradigm mentioned earlier) fails "to provide any mechanism for producing the vastly larger number of smaller earthquakes" (Geller et al., 2016: 126). Finally, they've pointed out that the forecasting of hazards through probabilistic seismic hazard analysis (PSHA) often conflict with

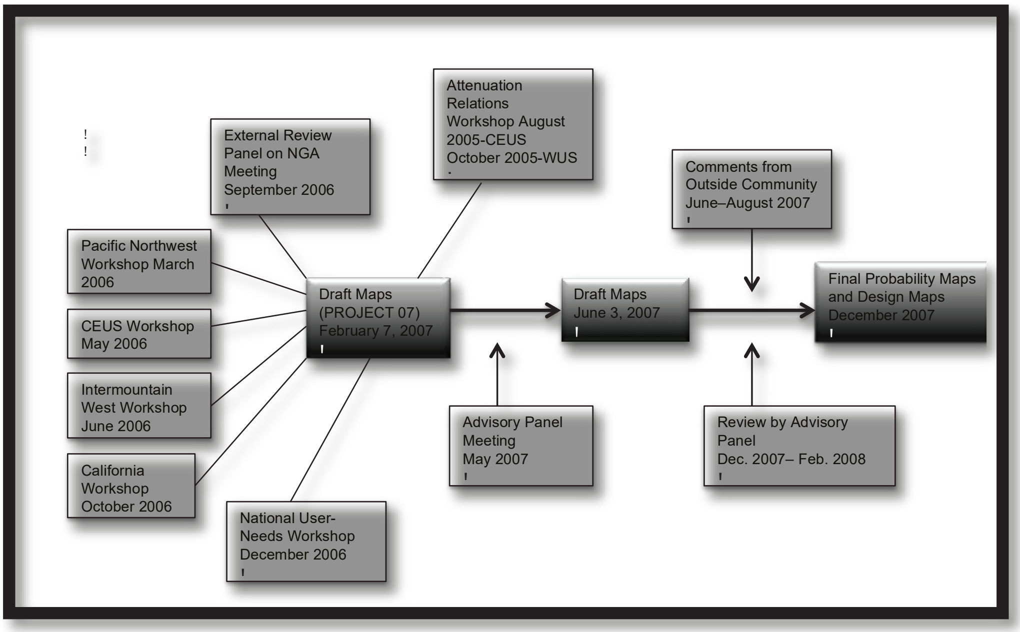

Figure 2. Process for developing the 2008 USGS National Seismic Hazard Map. CEUS, Central United States (Petersen et al., 2008).

observational data in such way that it does not "make it possible to produce reliable hazard maps" (Stark, 2017). As a consequence, they recommended that Bay Area residents should "largely ignore the USGS probability forecast," but rather" take reasonable precautions, including bracing and bolting their homes as well as securing water heaters, bookcases, and other heavy objects. They should keep first aid supplies, water, and food on hand" (Stark and Freedman, 2009: 126).

Contested scenarios, and the map that represent them, are not the final step of construction of earthquake risks; instead, they are just a starting point. Despite its weaknesses, the Seismic Hazard Map has performative capacities: it "does not simply describe an external reality 'out there': (it) also take(s) part in working upon, modifying, and transforming that reality" (Asdal, 2015). As researchers in Geography and STS have noted, a map is a space of conflict and negotiation: the visualization of the risk (however imperfect it is) and the geographical space that it represents co-construct each other: "risks transform spaces and (…) spaces subsequently lead to changes in the nature of risks themselves" (November, 2008: 1523). In practice, the Seismic Hazard Map operates as a major instrument of risk prevention that feeds policy planning at the federal level: it is included in recommendations by the National Earthquake Hazard Reduction Program[15] (NEHRP), and plays a significant part in the creation of buildings codes[16] by the Building Seismic Safety Council[17] (BSSC) and in the retrofitting guidelines designated by the Federal Emergency Management Agency (FEMA). The map is also an important source of information for the financial sector: the California Earthquake Authority (CEA) uses it to define premiums for state insurance program and financial companies, such as the pension funds who take earthquake risk very seriously in portfolio construction.

Maps such the Seismic Hazard Map should therefore be considered has "navigation platform" that are not true representation of the world, but establish a system of "correspondences" (November et al., 2010) indicating salient makers, the "altered equilibrium" that need to be operationalized in practice. As a performative object, the Seismic Hazard Map imposes its reality on others by deploying, in a single moment, the complexity of its composition, its own existence. This capacity of data translation and communication is pivotal in the risk definition: an only partially 'immutable mobile' (Latour, 1990).

Mode of existence 3: The transformative experience of the earthquake as "a living agent"

Direct experience of earthquakes is one way of knowing what it is to live in a seismic zone.[18] Experience of the intensity of an earthquake depends not only on the observer distance to the epicenter but also on the crustal material that seismic waves must travel through. For the observer, the feeling of the earthquake also depends on the type of building he may be standing in and the quality of the observer's attention to the phenomenon.[19]

The perception of the floor, walls, and other surroundings—all moving, and the ground falling away under one's feet—along with a definite feeling of spatial disorientation: an earthquake is happening. The feeling of "solid ground" now in motion is deeply unsettling. While droping, covering, and holding, the idea that of an earthquake slowly makes its way through the nervous system. "Earthquake!"—but then, "How big?" In his post-earthquake account, the philosopher William James described his own experience, recalling a California friend's warning about the possibility of a seismic event:

> Accordingly, when, lying awake at about half past five on the morning of April 18 in my little "flat" on the campus of Stanford, I felt the bed begin to waggle, my first consciousness was one of gleeful recognition of the nature of the movement. "By Jove," I said to myself, "here's B's old earthquake after all"; and then, as it went crescendo, "and a jolly good one it is too!" I said. Sitting up involuntarily, and taking a kneeling position, I was thrown down on my face as it went fortior shaking the room exactly as a terrier shakes a rat. Then everything that was on anything else slid off to the floor, over went bureau and chiffonier with a crash, as the fortissimo was reached; plaster cracked, an awful roaring noise seemed to fill the outer air, and in an instant all was still again, save the soft babble of human voices from far and near that soon began to make itself heard, as the inhabitants in costumes négligés in various degrees sought the greater safety of the street and yielded to the passionate

> desire for sympathetic communication. The thing was over, as I understand the Lick Observatory to have declared, in forty-eight seconds. To me it felt as if about that length of time, although I have heard others say that it seemed to them longer. In my case, sensation and emotion were so strong that little thought, and no reflection or volition, were possible in the short time consumed by the phenomenon. (James, 1906: 1215 -1216)

Taking a broad view, earthquakes are what happen when familiar categories lose their everyday, common properties; when they are moved suddenly and without warning. It is a moment where the "Order of Things" (Foucault, 1970), the well-established ordinance of the world as we know it, is transformed. Objects, time, values, space, thinking, and emotion: everything changes substance. Every "thing" becomes a mass, moved by gravity, and the human body is one of them. Of course, the process of a rumbling earthquake is, in fact, usually very quick, often not lasting more than a couple of seconds.[20] But these few seconds can be life-changing. Writing to his brother Henry after the earthquake, James declared: "[It is] impossible not to feel it as animated by a will, so vicious was the expression of the temper displayed, and I see now how absolutely inevitable was the primitive theological interpretation of such disturbance" (Livingston, 2012) —a disturbance so large that it also impacts the categories of human and non-human, physical and meta-physical.

For residents of seismic zones, the contour and intensity of earthquake risk are partly defined by the spatial and emotional traces that past disasters leave behind them, creating an invisible map of dangers, memories, and emotions. In After the Quake (Murakami, 2002), Murakami's characters live through what psychologists call a "post-traumatic experience," which unfolds in several steps. Here, the description of the effects of an earthquake on the characters portrays the "mysterious and profound way" in which those changes operate (Rosbrow, 2012). Psychoanalyst T. Rosbrow, reflecting on the Murakami pieces, describes its development as "first, strangeness—the loss of the familiar; second, the past intruding into the present with the physical/emotional sense of being 'shoved'; and third, most importantly, the sense of randomness that follows in the wake of traumatic events, which wipe out our needed sense of predictability and order" (Rosbrow, 2012). After the Loma Prieta Earthquake in 1989, many in the Bay Area were deeply shocked in a way similar to Rosbrow's description. As one expert in post-earthquake evaluations observed during our discussions, "After the 1989 Loma Prieta Earthquake, about three days after, I woke up in a sweat. Like, 'Oh my God, I have to get out of here!" Another scientist confirmed:

> I don't know if [the experience of the earthquake] basically changed me, but I know that I had been in number of damaged areas caused by earthquake shortly afterward. I find that those trips had a major effect on me, in terms of considering how serious earthquake risks are, and their consequences. I think it caused me to look at what the consequences are in society and the value that society has.

Connecting science and experience, the past and the future, the collective and individual, direct or indirect experiences of earthquakes have a strong impact on the human soul. "If an earthquake is what happens beneath the ground, beyond our sight and immediate comprehension, then so too are our individual lives shaped by psychological and emotional tremors that we find hard to grasp, and subject to numerous unpredictable and violent aftershocks." (Clark, 2002). Living with the risk of earthquakes—waiting, as well as planning, for the next "Big One"—allows earthquake experts and scientists to add a layer of lived experience to their scientific knowledge. As one of the persons interviewed recalled:

> As a seismologist, I individually think of earthquakes from a purely scientific perspective. That obviously builds into understanding what the likely effects of earthquakes are. As an individual and regular person living in the Bay Area, I am interested to know the kind of very real impact an earthquake would mean for me. I think that's an important combination; a lot of seismologists are spread around the world working on earthquake hazards wherever they are, but actually living in an earthquake zone forces you to combine the scientific aspect [with] the personal and societal aspects.

During my fieldwork, I have observed that, building on years of expertise and experience, experts and scientists interested in understanding, mitigating and preparing for disaster have used their intimate and multidimensional knowledge of the phenomenon—how it felt, how it displaced things, how it changed the landscape—as a basis for scientific inquiry. The introduction of these non-rational dimensions ultimately opens up new perspectives in the definition and organization of our worlds: it allows existences—or ontologies—of actants that were not previously visible to come into being. With time, these experts and scientists whom I have interviewed and those who participated the post Fukushima workshops have come to recognise that their knowledge and their experience are interwoven, giving them some responsibilities toward their fellow residents. While observing the consequences of catastrophe unfolding and imagining the ones to come, they have defined the contours of an hybrid form of sense- and knowledge-making.

Facing the complexity, the messiness, and the unknown existence of the earthquake as a "living agent", trying to answer difficult questions that for most do not have any clear answer, they to be became scientists-citizen, or amateurs with "passionate interests"(Latour and Lepinay, 2009) who learn to be affected and care about technicalities (Mol, 2010) and, as Emilie Hache suggested, are able to tap into the reservoir of our collective emotions to describe the world and take action. For this community of experts, living through the routine moments of everyday life in a seismic zone, sharing the common fate of a potential threat and building infrastructures that can help mitigate the risk, has been a transformative experience.

Conclusion

Earthquakes produce movement: the movement generated by tectonic plates, but also the movement provoked by the response to the earthquake. During the workshops that I attended in the aftermath of the Tōhoku earthquake and tsunami and the Fukushima Daiichi disaster, and while speakers were presenting their work, it became clear to me that the event we were discussing had multiple existences, multiple ways of "being into the world," which were hard to reconcile. This apparent diversity of experiences is reinforced by the many ways in which the narration, the stories, and the analyses of the event were performed across disciplinary fields and epistemologies. As is often the case in risk and disaster studies, much of the work presented was built on what can be described as the "fifty shades" (Strasser and al., this issue) of citizen science: a variety of research programs and methods sometime relying on nonscientists to collect and analyze data, and often sharing their data in order to increase public understanding of science and to impact public policies. Each contribution looked at distinct existences of the disaster that, far from being antithetical to each other, showed kaleidoscopic facets, imagination, and epistemologies of the same event.

Science and Technology scholars have noted that nineteenth-century scientists have "take(en) out the human element from the research, to make the research processes and products objective" (Strong, 2008), thus making the multiple agency, the actants, the mode of existence, that "interfere" with the scientific process invisible and, in the same movement, taken away the complexity of the subjectivity of the scientist as a knowing subject (Houdart, 2008; Mialet, 2012a). In my research I have observed that the everyday company of earthquakes, even those yet to be, is an experience strong enough to hybridize knowledge and change the nature of expertise. A century after the 1906 earthquake, this interpretive move is still a work in progress as contemporary seismologists continue to revisit past events and engage with scientific communities and the public. In this paper, I have tried to show how the distinct existences of the earthquake require distinct assemblages of collaboration between scientists and nonscientists, using different type of data and infrastructures to emerge.

The first mode of existence focuses on the observation and translation of multiple mechanism that are responsible of the earthquake: if the contours of the "tensions in the earth's crust reach the breaking point" are hard to delimitate and multiple methods are still needed to comprehend the complexity of the phenomenon, collaboration between non-scientists and scientists is part of the solution. The second mode of existence addresses another iteration of the existence of the earthquake, its visualization and translation into a quantifiable risk. In this section, I have showed that, in that form, the earthquake was gaining another existence with performative abilities, able to stabilized a contested snapshot of the definition of the "altered equilibrium". The third mode of existence is addressing the more personal and affective dimension of the earthquake as a "living object". This existence is certainly the most difficult to grasp, but it is also the mode where emerge the non-rational dimension of knowledge and where intersection of citizen a non-citizen science is the most interesting, offering the opportunity to imagine a continuum of knowledge that include academic practices as one important but certainly not unique way of sense-making.

In recent years, as scientific infrastructure evolves, data used by earthquake scientists, observers and concerned citizens have come from disparate systems of measurements: each system allows us to look at the movement of tectonic plates from particular angles and perspectives. Quantification by means of instrumentation has often taken precedence over eyewitnesses' perceptions, but despite this considerable progress, earthquakes remain hard to grasp, and are calling for other modes of existence, other assemblages. In a world that has become increasingly datafied, where the conditions of knowledge-making are transformed to the point where researchers start evoking a change of paradigm for their discipline (Hey et al., 2009), the questions of the modes of sciences, redistribution of research and methods become crucial articulation to observe, analyze and in cases critic. In the context of disasters, the focus on the collective good (for the preparedness and preservation of the multiple cities of the Bay Area) has (in some places) brought about a shifting of hierarchies of knowledge: scientists now allow themselves to become amateurs, paying attention to several modes of existence—several ontologies—of the earthquake and the earthquake risk as they emerge in a situated manner. More research needs to be conducted to understand how the interaction between data structures, infrastructures, institutions on one side and workflow and repertoires on this other, enables or constrains the emergence of new modes of existence. In this context, datafication, often thought of as a quantitative approach, must be integrated to clarify the messiness of heterogeneous data, or whatever else might be given by experience.

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Notes

1 That day, the panel discussion included among others Peter Hayes, Nautilus Institute, USF; Joonhong Ahn, Nuclear Engineering, UC Berkeley; Mary Comerio, Architecture, UC Berkeley; Cathryn Carson, Professor, History and then–Associate Dean of Social Sciences, UC Berkeley.

2 While experts in conference rooms were pleading for democracy, the case for science was far from being settled in other public spaces. Debates raged about the scientific assertions and assumptions of the possible impact of radioactivity on the Bay Area. Pieces of information were collected by residents from all around the globe. Social media provided a platform for the dissemination of alternative information and independent research (Abe, 2013) at a time when official information was substantially lacking. (Slater et al., 2012)

3 This panel had been put together with the precious support of Prof. Joonhong Ahn (1958 –2016), member of the Nuclear Engineering Department, and Faculty Member of the Center for Japanese Studies within the Institute of East Asian Studies. Professor Ahn's dedication to the question of resilience and to STS approaches made his contribution to the field unique.

4 Which was, it itself a form of citizen science project, built around book and an interactive platform on which Mediators, Collaborators and Co-researchers were collaborating to define different modes of existence.

5 As Star and Griesemer noted almost three decades ago, "[M]ost scientific work is conducted by extremely diverse groups of actors—researchers from various disciplines, amateurs and professionals, humans and animals, functionaries and visionaries. Simply put, scientific work is heterogeneous." (Star and Griesemer, 1989: 391-392)

6 The concepts were developed by French philosopher Etienne Souriau in the 1940s and rediscovered by Bruno Latour and Isabelle Stengers in recent years (2009). Souriau, a philosopher of aesthetics interested in the emergence of the work of art, developed concepts of "instauration" which, more than being simply the transformation of raw material into an artistic object, described the progressive institution and discovery of multimodal interactions during the laboring process of creation.

7 "According to these theories, earthquakes were due to the sudden release of strain that had been gradually built up by the constant creeping of the earth's surface near a fault. In his contribution to the commission's final report, Harry Fielding Reid had argued that there has indeed been a gradual distortion of the earth's surface near the San Andreas Fault during the late nineteen century, just as the elastic rebound theory called for (Geschwind, 2001: 60-61)."

8 The Modified Mercalli Intensity Scale is still used today in the Shake Map, also known as the "Did You Feel It?" map.

9 Only after tectonic plate theory was largely accepted by the scientific community in the 1960s were seismologists able—and even today only partially - to describe and explain the mechanisms that trigger an earthquake.

10 The Japan Meteorological Agency seismic intensity scale measuring seismic coefficient known as *shindo,* which measure strength of earthquake ground motion, is still the wildly used in Japan.

11 http://earthquake.usgs.gov/dyfi

12 Cornell University; Lehigh University; Oregon State University; Rensselaer Polytechnic Institute; SUNY, Buffalo; University of California, Berkeley; University of California, Davis; University of California, Los Angeles; University of California, San Diego; University of California, Santa Barbara; University of Illinois, Urbana-Champaign; University of Minnesota; University of Nevada, Reno; and University of Texas, Austin.

13 Both the Lick Observatory and the Student's Observatory in Berkeley were equipped with two Ewing and one Gray-Milne seismographs.

14 To reiterate, the NSF is the National Science Foundation, and the NIST is the National Institute of Standards and Technology.

15 "The activities of the Program shall be designed to: (A)[…] research and develop effective methods, tools, and technologies to reduce the risk posed by earthquakes to the built environment, especially to lessen the risk to existing structures and lifelines; (B) improve the understanding of earthquakes and their effects on households, businesses, communities, buildings, structures, and lifelines, through interdisciplinary and multi-disciplinary research that involves engineering, natural sciences, and social sciences; and (C) facilitate the adoption of earthquake risk reduction measures by households, businesses, communities, local, state, and federal governments, national standards and model building code organizations, architects and engineers, building owners, and others with a role in planning for disasters and planning, constructing, retrofitting, and insuring buildings, structures, and lifelines through: (i) grants, contracts, cooperative agreements, and technical assistance; (ii) development of standards, guidelines, voluntary consensus standards, and other design guidance for earthquake hazards risk reduction for buildings, structures, and lifelines; (iii) outreach and information dissemination to communities on location-specific earthquake hazards and methods to reduce the risks from those hazards; and (iv) development and maintenance of a repository of information, including technical data, on seismic risk and hazards reduction"(112th Congress 1st Session, S.646 To reauthorize Federal Natural Hazards Reduction Programs and for others purposes, In the Senate of the United States, March 17, 2011).

16 The building code has been adopted by 37 states, including California.

17 The BSSC, established by the National Institute of Building Sciences, develops and promotes building earthquake mitigation regulatory provisions for the whole nation.

18 Of course, the human body does not perceive all earthquakes, and the experience of an earthquake can be indirect. But very small earthquakes, such as those at M2.5 and less, that might not be perceived by the human body are recorded and are visible on the Real Time USGS maps. Therefore, tremors that are neither humanly perceived nor recorded through instruments do not "exist" as earthquakes.

19 Comparing experiences can fuel conversations for a while. For many, it is often interesting to think about and discuss what they experienced: the growing rumble of the P waves or the shock of the S waves.

20 Very occasionally, however, they can be surprisingly long; the Tōhoku earthquake, for example, lasted approximately six minutes.

“Citizen Science”?
Rethinking Science and Public Participation

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Abstract

Since the late twentieth century, “citizen science” has become an increasingly fashionable label for a growing number of participatory research activities. This paper situates the origins and rise of the term “citizen science” and offers a new framework to better understand the diversity of epistemic practices involved in these participatory projects. It contextualizes “citizen science” within the broader history of public participation in science and analyzes critically the current promises—democratization, education, discoveries—emerging within the “citizen science” discourse. Finally, it maps a number of historical, political, and social questions for future research in the critical studies of “citizen science.”

Keywords: public participation in scientific research, history of science, science and technology studies

Introduction

There is probably no such thing as “citizen science,” yet there might be a few questions to ask about it (*after* Shapin, 1996). The expression has become increasingly popular in the general media and in science policy discourses since the beginning of the twenty-first century, first and foremost in the United States and Europe, but now also in Asia and the Global South (Chandler et al., 2012; Kera, 2015; Pham et al., 2015). The term “citizen science” is currently used in the media to designate a wide range of practices, from citizens donating the processing power of their personal computers to perform scientific calculations (SETI@home), to amateur naturalists collecting observational data outdoors about birds (eBird), city residents mapping air pollution (City Sense), people classifying online images of galaxies from home (Galaxy Zoo), patients sharing quantified observations, symptoms, and experiences about their health (PatientsLikeMe), and biohackers attempting to produce insulin in a community laboratory (Counter Culture Labs). A growing number of organizations and institutions carry it in their name (there is even a journal devoted to it). It is still unclear whether the diverse practices subsumed under that heading form a coherent whole, let alone a cohesive social movement, or even if they grew out of a single historical tradition. In this essay, we will outline some of the intellectual challenges raised by the rise of "citizen science," especially with regard to their place in the longer history of public participation in science (Lengwiler, 2007).[1]

Even if we sound somewhat distrustful about the reality of a thing called "citizen science," the rise to prominence of the term in contemporary discourse is beyond doubt and hugely interesting historically, politically, culturally, and epistemologically. It points to a potential transformation in the modes of public participation in science.[2] Contemporary discourses on public participation in science, including "citizen science," are challenging a number of founding elements of the modern regime of knowledge production based on the separation between expertise provided by professional scientists working in dedicated research institutions and the lay public understood as a consumer of scientific knowledge and technologies. In many cases, participatory research projects question *who* can produce legitimate scientific knowledge, *how* it is produced, *where* it is produced, and sometimes *why* it is produced. Thus, participatory research is not necessarily just "science by other means," but could refocus what parts of the natural and social worlds are subject to scientific inquiry, thereby transforming *what* we know about the world. The rise of participatory modes of scientific research constitutes a challenge not only to present science but also to the current social order, providing yet another example of the coproduction of science and society (Shapin and Schaffer, 1985; Jasanoff, 2004). In this perspective, examining the rise of participatory research is as much a window into the transformation of modern science as it is into the transformations of contemporary societies (Chilvers and Kearnes, 2015).

In this discussion essay, we attempt to make sense of the current discourse on "citizen science," successively questioning the definitions, genealogies, and promises that have been put forward by its practitioners, promoters, and analysts. In the course of this examination, we spell out a number of research questions that the history of science and STS should, and are well equipped to, tackle. Such a research program will need to challenge the singular of "citizen science" in order to offer a fine-grained analysis of the variety of epistemic practices subsumed under that common expression. Only such an analysis will provide the basis for meaningful genealogies of "citizen science," genealogies that go beyond the allusions, hat in hand, to the amateur naturalists of the nineteenth century or to the radical science movements of the sixties. Finally, understanding what kind of science, but also what kind of society, this particular mode of public participation in science is producing will require joining the epistemological with the political.

What is "citizen science"?

Origins of the Term "Citizen Science"

Science policy analyst Alan Irwin and ornithologist and participatory research organizer Richard Bonney are often credited with coining the term "citizen science" (Irwin, 1995; Bonney et al., 1996). However, Irwin's original conceptualization differed in important ways from Bonney's (Riesch and Potter, 2014; Cooper and Lewenstein, 2016) and, more importantly, from the current usage. In Irwin's 1995 book *Citizen Science: A Study of People, Expertise and Sustainable Development*, "'Citizen Science' … conveys both senses of the relationship between science and citizens" (Irwin, 1995: xi). One the one hand, "citizen science" is a science that serves the interests of citizens (like "military science" serves the interests of the military), while on the other, it is a science performed by citizens (like "professional science" is performed by professionals). In short, both senses refer to "science *for* the people" and "science *by* the people." The book's recommendations are mainly focused on the first notion, aiming at making science policy more responsive to people's "understanding" and "concerns" thus making science policy more "democratic" (Irwin, 1995: 69–80). The book was published in the midst of the British debates about the value of "public understanding of science," just three years after the launch of the eponymous journal. When addressing the second notion, Irwin's emphasis was on "local" and "contextual" knowledge produced by citizens, which differs qualitatively from knowledge produced in scientific institutions. His concern echoed the debates then taking place in science and technology studies and feminist epistemology about "indigenous knowledge" (Watson-Verran and Turnbull, 1995) and "situated knowledge" (Haraway, 1988). Irwin wanted these voices and forms of knowledge—and not only those of scientific experts—to be taken into account in deliberations about technological risks and science policy. Although Irwin's work is often cited in reference to current practices labeled as "citizen science," it is more of a reflection on the participatory ideals—and their limitations—of the 1970s than on the practices currently subsumed under the label "citizen science," which focus on the production of scientific knowledge outside of scientific institutions, but mostly following the norms and values of institutional science.

Richard Bonney's (1996) notion of "citizen science" pointed in a different direction. Since 1992, he has been supported by a National Science Foundation (NSF) grant to study the educational role of "Public Participation in Ornithology," following up the long tradition of amateur ornithology (Barrow, 1998). Four years later, he defined "citizen science" as scientific projects in which "amateurs" provide observational data (such as bird spotting) for scientists and acquire new scientific skills in return, "a two-way street" (Bonney, 1996). By 2001, the NSF was developing policies to complement "public understanding of science" with "public understanding of research" (Field and Powell, 2001). The subsequent year, through its new Informal Science Education program, it began supporting initiatives that "involve the public in scientific research" (National Science Foundation, 2002: 7), a goal it reformulated in 2004 as allowing "participants to contribute to ongoing scientific research as in citizen science" (National Science Foundation, 2004) and supported numerous such initiatives in the following years. As Bonney would put it in 2016, regarding science education "Citizen science was the magic bullet the NSF was looking for" (Bonney, 2016).

Bonney (and the NSF) viewed "citizen science" as both public participation in scientific research *and* a tool to promote the public understanding of science (killing two birds with one stone). To a large extent, this view reflects current practices that fall under the heading of "citizen science," even if the attention to education varies from case to case. In 2013, the SOCIENTIZE Expert group for the European Commission's Digital Science Unit defined "citizen science" in a similar way: "Citizen science refers to the general public engagement in scientific research activities when citizens actively contribute to science either with their intellectual effort or surrounding knowledge or with their tools and resources" (Socientize, 2013: 6). The main goal, however, was to educate the public, as the coordinator of the European Expert group put it: "One of the best ways to help people understand science is by letting them participate in scientific research and experiments. This is what citizen science tries to achieve" (Serrano, 2013). In 2014, the Oxford English Dictionary added an entry for citizen science (without mentioning, however, its educational feature): "citizen science: n. scientific work undertaken by members of the general public, often in collaboration with or under the direction of professional scientists and scientific institutions" (OED, 2014).

The specificity of the current understanding of "citizen science," as a mode of public participation in science, is the claim that *amateurs* ("general public") can contribute to the *production* of *scientific* knowledge, with education as an associated goal or a by-product. A variety of other terms have been used to designate practices that fit, at least partially, the current definition of "citizen science," including "participatory research," "community-based research," "science 2.0," "open science," "amateur science," and many others. Though the meaning and history of these terms do not perfectly overlap, they all encompass participatory practices aiming at including non-professionals in the making of scientific knowledge (the notions of "amateur," "lay person," "general public" or "non-professional" are of course problematic and will be discussed below). "Citizen science" is best understood as a recent and increasingly fashionable label applied to a subset of initiatives promoting "public participation in scientific research" (Shirk et al., 2012).

Typologies of "Citizen Science"

Practitioners, promoters, and analysts of "citizen science" have proposed a number of different typologies to make sense of the variety of practices that the expression encompasses. These typologies have mainly emerged in the context of evaluation practices carried out by the organizers of "citizen science" projects themselves and science funding agencies. More rarely, these typologies have been the result of academic research in science studies, which have contributed to evaluating these projects and defining what "citizen science" should be. Like all typologies, they reflect normative commitments about the values and hierarchies among various kinds of activities.

The most common kind of typology of participatory projects has focused on the locus of power. The typology devised by an NSF-sponsored inquiry group led by Richard Bonney distinguishes "contributory projects," which are "designed by scientists" and where the public "primarily contributes data," from "collaborative projects," where the public can also "refine project design, analyze data, or disseminate findings," and from "co-created" projects which are "designed by scientists and members of the public" and "at least some of the public participants are actively involved in most or all steps of the scientific process" (Bonney et al., 2009: 11). This typology creates an implicit hierarchy that places "co-created" projects as a superior mode of "citizen science," since it goes further in involving the public's participation, echoing public policy analyst Sherry R. Arnstein's (1969) influential "ladder of participation" developed in the context of participatory urban planning. This typology was later expanded into five modes (contractual, contributory, collaborative, co-created, and collegial) according to the "degree of participation" (Shirk et al., 2012), but this time the authors were careful to avoid any hierarchical interpretation, insisting that they represented a "spectrum." This approach to classifying participatory activities according to "degrees of participation" has also been adopted by geographer and participatory research advocate Muki Haklay into a model of different "levels of participation," a "ladder" (and even an "escalator") from "crowdsourcing" (distributed computing and data gathering) to "extreme citizen science" where citizens have the most agency and "are involved in deciding on which scientific problems to work on" (Haklay, 2013a: 117). These kinds of typologies have a clear political agenda: to encourage projects fulfilling citizen empowerment, rather than exploitation while ensuring that they contribute to science, as defined by scientists.

Alternative typologies have focused for example on the goals of the participatory projects as well as the environments in which they are carried out. Information scientists Andrea Wiggins and Kevin Crowston (2011) distinguish five types of "citizen science": "action" (reaching local civic agendas through science), "conservation" (natural resource management), "investigation" (data collection in a natural environment), "virtual" (online scientific research projects), and "education" (science education in formal and informal settings). This typology places a greater emphasis, and value, on place and locality in participatory projects, highlighting participatory projects carried out in the physical world and distinguishing them from the "virtual" projects carried out online which have, due to their technological novelty, received the most attention in the media.

We propose a rather different typology of the practices that have been labeled "citizen science," distinguishing between five *epistemic* practices, which we identified expanding on an initial classification developed by physicist and participatory research organizer François Grey ("volunteer thinking," "volunteer sensing," "volunteer computing," Grey, 2012). Our five epistemic practices involved in participatory research—sensing, computing, analyzing, self-reporting, making—help us see beyond the recent initiatives carrying the label "citizen science" and capture the greater diversity of participatory practices, past and present (for an illustration of each of these different epistemic practices, see the five vignettes). This typology does not imply any hierarchy between the different kinds, they are simply qualitatively different, and often hybrid, modes of knowledge production. These practices are ideal types, not natural kinds that could uniquely define the "nature" of participatory projects. Their purpose is to help us analyze (not classify) participatory projects in terms of their different knowledge practices. "Sensing," for example, might be a dominant practice in a nature observation project, which also involves "analyzing" data and "making" instruments as a more minor component. This typology, like all typologies, has an agenda: by staying close to the actual knowledge practices of the actors, it avoids presupposing that they are all related and forms a thing called "citizen science."

Sensing. In 2002, the Cornell Lab of Ornithology and the National Audubon Society launched eBird, an NSF-supported online platform dedicated to recording the migration of birds: "Keep track of the birds you see anywhere in North America" ordained their website at that time (eBird, 2002). The data collected by the participants contributed to a "cumulative eBird database" to be used "by birdwatchers, scientists, and conservationists who want to know more about the distributions and movement patterns of birds across the continent."

By September 2017, participants had reported more than 400 million bird observations on all continents of the globe. Today, hundreds of similar projects are available worldwide. They draw on people's familiarity with their local environment and the fact that large numbers of participants can greatly expand the spatial reach of observational projects. These projects range from eye observations of floods in the UK (Floodcrowd, 2016 – "citizen science study into flooding in the UK") or road signs in Luxembourg (Lingscape, 2016 – "Citizen science meets linguistic landscaping") to air quality monitoring through smartphone embedded sensors in the US (Common Sense, 2009 – "use sensing technologies to conduct citizen science and participate in the political process"). Most are available through smartphone apps and therefore follow people in their everyday lives.

Computing. In 1996 at the Fifth International Conference on Bioastronomy, a group of scientists announced that they were designing "an innovative SETI [Search for Extra-Terrestrial Intelligence] project (..) involving massively parallel computation on desktop computers scattered around the world" (Sullivan et al., 1997). Two years later, SETI@home was launched, under the direction of the University of Berkeley computer scientist David Anderson, and soon attracted millions of participants who "donated" the idle cycles of their desktop computers' CPUs in order to analyze radio signals that might indicate the existence of extraterrestrial intelligence. In 2005, the original SETI@home gave way to BOINC (Berkeley Open Infrastructure for Network Computing), a platform which allowed participants to choose between many different science-related projects, such as Rosetta@home (protein structure prediction) or MalariaControl.net (simulation models of the transmission dynamics and health effects of malaria), among many others. Although these projects are more commonly referred to as "volunteer computing" projects—a term coined in 1996 by the computer scientist Luis F. G. Sarmenta at MIT (Sarmenta, 2001)—they are now retrospectively cast as the forefathers of contemporary "citizen science" projects (Wright, 2010; Hand, 2010), or simply as "citizen science" projects in their own right (Holohan, 2013), even though the expression is rarely used by the members of the BOINC community.

Analyzing. In 2006, a NASA spacecraft landed back on earth, quite dusty after spending almost seven years in space. Scientists from the UC Berkeley Space Sciences Laboratory hoped that among millions of specks of dust a few might be of interstellar origin. To accomplish this massive quest, they launched the web platform Stardust@home, "a distributed search by volunteers for interstellar dust," where participants could operate a "virtual microscope" to identify these rare particles from online images (Stardust, 2006). The following year, the Education and Public Outreach Specialist of Stardust@home named it "a citizen science project" (Méndez, 2008). Since then, a number of similar projects have emerged, such as Galaxy Zoo (2006)—determine the shape of galaxies—or Penguin Watch (2014)—count penguins in large colonies—many of which are present on the Zooniverse web platform, founded by astrophysicists Chris Lintott and Kevin Schawinski at the University of Oxford, "home to the internet's largest, most popular and most successful citizen science projects" (Zooniverse, 2009). Since 2005, these projects have also been designated as "crowdsourcing" (Howe, 2005; Brabam, 2013) and cover a wide range of tasks, such as classifying images like in Galaxy Zoo, or analyzing existing scientific data by playing games like in the Foldit project (2008), where people fold proteins in three-dimensions.

Self-reporting. Riding on the success of medical information websites and social networks, several medical research platforms were created at the beginning of the twenty-first century. Among the most popular are the social media health platform PatientsLikeMe (2004), the direct-to-consumer genomic service 23andMe (2006), and the microbiome research company uBiome (2012). These platforms invite their participants/consumers to share and compare both qualitative (self-reported symptoms and illness-narratives) and quantitative data (patient records, genomic and other laboratory test results, and self-tracking health data). The information is then pooled for research purposes. The projects are advertised through "participatory" slogans such as "Let's make health care better for everyone through sharing, support, and research" (PatientsLikeMe, 2016) or "Join the thousands of citizen scientists who have had their microbiome sequenced" (uBiome, 2016).

Making. In 2010, a group of biologists and entrepreneurs from the San Francisco Bay Area created BioCurious, a space which they defined as a "Hackerspace for Biotech" and a "Community Lab for Citizen Science" (Kickstarter, 2010). In order to pay the rent of their 3,000 square-feet space located in an industrial building in Silicon Valley, and "dedicated to Non-Institutional Biology," they launched a financing campaign on the crowdfunding platform Kickstarter asking people to "forgo that skinny soy pumpkin soy latte for A DAY, and pledge toward the advancement of Citizen Science!" (Kickstarter, 2010). In the following years, BioCurious hosted a number of scientific projects, ranging from making plants that would glow in the dark to producing vegan cheese by genetically engineering yeast to produce milk proteins. The latter project was carried out in collaboration with another laboratory, Counter Culture Labs, a "Community Lab for biohacking and citizen science" that had been set up in Oakland, California in 2013, by a "community of citizen scientists" (Counter Culture Labs, 2013). Since 2010, a number of similar spaces, often under the heading of "do-it-yourself biology" (DIYbio), or "biohacking," have been established in large cities in the United States and Europe, such as Genspace in Brooklyn, NY, "a non-profit organization dedicated to promoting citizen science and access to biotechnology in the greater New York Area," and La Paillasse in Paris. Often inspired by computer hacker spaces and foregrounding the "hacker spirit" (Himanen, 1999; Delfanti, 2013), these spaces illustrate epistemic practices based on "making" things and producing knowledge in laboratories.

This typology also draws attention to practices *not* carried out under the banner of "citizen science," such as "participatory action research" and "community-based research," but that might nevertheless be essential to understanding public participation in the production of scientific knowledge. Unlike other typologies, such as the "ladders of participation," the one presented here, based on epistemologies, makes no assumptions about the kinds of politics enacted by different kinds of "citizen science" projects, leaving the question of the links between epistemologies and politics as an empirical question. The goal of this typology is not taxonomic, but fundamentally analytic: by analyzing the variety of public participation projects in terms of their individual epistemic components, the individual genealogies of these "ways of knowing," as John Pickstone (2000) has put it, can be disentangled.

Situating "citizen science" historically

Although most exponents of the different kinds of "citizen science" frame them as an unprecedented or revolutionary movement emerging at the end of the twentieth century, they sometimes acknowledge the existence of two historical precedents: the tradition of amateur naturalists in the eighteenth and nineteenth century and the critique of science of the late 1960s and early 1970s (Dickinson et al., 2010; Silvertown, 2009; McQuillan, 2014). These two historical filiations deserve critical scrutiny (for another attempt at historicizing the transformation of public participation in sciences, see Lengwiler, 2007).

Amateur Naturalists

Drawing a simple connection between amateur naturalists and current "citizen science" can be misleading and obscure two crucial aspects that make present forms of public participation in research, including "citizen science," historically significant. First, the concept of "citizen science," as a relationship between professionals and amateurs focused on the production of scientific knowledge, only makes sense after professionalization has produced these mutually exclusive categories, a process which took place during the nineteenth century and only solidified by the end of that century (Mody, 2016; Allen, 2009). Before that, most "natural philosophers" and "naturalists" (then "men of science," "savants," and "Naturforscher") were many other things at the same time (White, 2016), and were mostly unpaid for their scientific occupation, which was often practiced only a few hours a day, aside from their main professional occupation. Science was mostly what one might call a "hobby" today, and those spending time producing natural knowledge were all "amateurs," even though not all amateurs were equally involved in their craft. Thus, before the mid-nineteenth century, almost all science was "citizen science" (Haklay, 2013a). Applying this notion to historical periods predating the professionalization of science is thus not particularly helpful analytically. However, the fact that this mistaken historical filiation is put forward today is interesting as an attempt at "inventing a tradition" (Hobsbawm and Ranger, 1983) that could legitimize today's participatory research: if Darwin was a citizen scientist (Silvertown 2009), then today's amateurs participating in science might also be up to something valuable.

For example, instead of thinking of public participation solely as a matter of expertise, with "amateurs" taking part in activities reserved to "experts," it might be more useful to conceptualize public participation in terms of space. From people sharing processing power from their personal computer for the SETI@home project to hackers making biological experiments in their garage or kitchen, these forms of public participation delineate a domestic space for science and a distinctive genealogy of public participation. Indeed, the home was, since the scientific revolution, a key place for the production of scientific knowledge, especially among natural philosophers developing experimental ways of knowing in the laboratory's ancestor: the domestic kitchen (Shapin, 1988). However, the importance of domestic spaces for science was not restricted to the house of experiment in seventeenth century England, and "domestic science" continued far into the nineteenth century (Opitz et al., 2016). Darwin carried out physiological experiments, anatomical dissections, and systematic observations from his country house, a place that blurred the boundaries between the public and the private, family and colleagues, work and leisure. So, Darwin certainly had something in common with current "citizen scientists," not as some kind of "amateur," but rather as someone performing research from home.

Yet, the bigger picture remains: after Darwin, the exclusion of science from the home was a key aspect of the professionalization of science and part of the deep historical transformation that separated living and working spaces (Prost, 1999). In the twentieth century, when scientific and technical practices took place in the home, they were the mark of the "hobbyist," not the "professional." Scientific and technical hobbies blossomed after World War II, from ham radio to home rocketry, and delineated a special space, essentially for men, in the family home (Haring, 2008). Understanding the history of public participation might thus require a greater attention to the locus of scientific practices and their cultural, political, and epistemic consequences. Thinking about participatory research in terms of "domestic science" might be at least be as illuminating as describing it as "citizen science."

The second element that makes current public participation historically significant pertains to the fact that even after the professionalization of science (and thus the creation of a meaningful category of "amateur"), professional "science" remained a heterogeneous category (Pickstone, 2000). By the late nineteenth century, an increasing number of men (and some women) were practicing science as a full-time occupation, were paid for it, and were being called "scientists," a term coined by William Whewell half-a-century earlier, by analogy with "artist" to designate collectively all "students of the knowledge of the material world" (Yeo, 1993; White, 2016). Nevertheless behind these attempts at unification, a number of dissimilar epistemic and social practices continued to coexist. In this regard, the (experimental) physicist, the naturalist, and the mathematician (to borrow Whewell's examples) did not have that much in common. Regarding their relationship with the public, the differences could not be more striking. In plant and animal taxonomy, geology, anthropology, and astronomy, a dense network of professionals and amateurs collaborated, especially with regard to the collection of specimens and observations (Strasser, 2012). The great botanical collections of William Jackson and Joseph Dalton Hooker at Kew Gardens (Endersby, 2008) and of Augustin Pyramus and Alphonse de Candolle at the Conservatory and Botanical Gardens in Geneva, were largely constituted from specimens contributed (and sometimes identified) by amateur naturalists. In Britain, a rich culture of working-class amateur botanists, meeting in pubs, contributed to the production of systematic knowledge (Secord, 1994).

In the experimental sciences, a very different situation prevailed. The epistemic and moral authority of the experimental sciences derived in part from the *exclusion* of the public from the place where knowledge was produced: the laboratory (Shapin and Schaffer, 1985). In addition, the more and more sophisticated and expensive instruments required to practice experimental research were increasingly beyond the financial reach of the general public. Although these two scientific cultures live on to the present day, from the late nineteenth century, the experimental sciences have come to dominate most areas of inquiry about nature, marginalizing the kind of sciences in which amateurs played the most important role (Coleman, 1971; Cunningham and Williams, 1992). Thus, the twentieth century saw a widening gap between professional (experimental) scientists and the public. As *Popular Science Monthly* put it in 1902, referring to the experimental sciences: "The era of the amateur scientist is passing; science must now be advanced by the professional expert" (Anonymous, 1902: 477). Science popularization was not just a neutral observer of this divide. It declared its intention to bridge it, yet contributed to sustaining it (Bensaude-Vincent, 2003). From the late nineteenth century, the decrease in public participation in science should thus be seen not only as a result of the professionalization of science, but also as a shift in the center of gravity of the sciences from one kind of epistemic practice, where amateurs were highly present, to another where they were mostly excluded (even though, in some cases, collaborations persisted; Alberti, 2001).

Noting the importance of this second factor (the decline in natural history and the rise of experimentalism) makes visible one of the most distinctive features of some of the current practices falling under the label "citizen science." There are indeed strong historical continuities between amateur ornithologists in the nineteenth century, contributors to the Audubon Christmas Bird Count in the twentieth, and participants in Cornell University's online bird mapping project, eBird, in the twenty-first century. However, one should not overlook the fact that current "citizen science" projects include not only time-tried participation of amateurs in the collection of observations, like the presence of birds, but also their participation in *experimental* research, a field from which they had been mostly excluded for more than a century. Participatory projects involving the public in research about protein folding or particle physics, fields in which there was no tradition of public participation to build on, could mark a significant historical transition. One of the most striking features of some of the current participatory projects, we suggest, is that in some cases, they begin to bridge the gap between science and the public in the *experimental* sciences, precisely where this gap has been the widest. Making sense of this historical transition will require embracing a historical perspective that deviates from the usual reference to nineteenth-century amateur naturalists.

Radical Science Movements

After the amateur naturalist, the other most common historical filiation drawn for "citizen science" goes back to the radical science movements of the 1960s and 1970s. This genealogy apparently makes sense since some of the current advocates of public participation in knowledge production, especially in do-it-yourself biology and environmental monitoring, are highly critical of academic and corporate science for not serving the public interest (Delgado, 2013; Wylie et al., 2014). In the immediate postwar period, such challenges to the authority of science and technology had been more limited in scope (Pessis et al., 2013; Jarrige, 2016), focusing on specific issues, such as nuclear fallout or nuclear war (Wittner, 2009), air pollution (Fleming and Johnson, 2014), and toxic molecules that were harmful for human health or the environment (Boudia and Jas, 2016). Rachel Carson's indictment of the pesticide DDT in her immensely popular book *Silent Spring* (1962) soon became a rallying cry for those questioning more broadly the role of science in society (Lear 1997) and fueled the growth of the environmental movement (Egan, 2007). In the 1960s, and especially in the context of the protest against the Vietnam War, the critiques from the anti-nuclear, the environmental, and the health movements began to coalesce into a broad critique of science and technology (Moore, 2008; Egan, 2007; Leslie, 1993; Beckwith, 2002).

In 1969, the American group Scientists (and Engineers) for Social and Political Action, better known through the title of the journal it started publishing the following year, *Science for the People*, began disrupting the annual meeting of the American Association for the Advancement of Science (AAAS), calling for a redirection of the research enterprise towards the needs of the people, rather than those of the "military-industrial complex" (Moore, 2008). In many ways, their call echoed those of the radical scientists of the 1930s, such as John Desmond Bernal in the UK and Walter B. Cannon in the US, but without explicit Marxist overtones (Ravetz and Westfall, 1981; Kuznick, 1987). Yet, the message of Science for the People activists was not always well received, at least not by "the angered wife of a respected biologist [who] thrust her knitting needle into the arm of a noisy young protestor" (Wilford, 1970). Science for the People also attempted, like other similar movements in France, to "educate the scientists" ("raise awareness" one might say today) about issues such as the researcher's working conditions, social inequalities, race, poverty and gender disparities (Debailly, 2015; Quet, 2013). The goal was to encourage the development of a community of "citizen scientists."

Although it might be tempting to see a deep connection between the "citizen scientists" envisioned by these radical science movements and the current discourse about the lay individuals becoming "citizen scientists," these two notions of "citizen scientist" actually point in opposite directions. In the 1970s, groups like Science for the People, mainly composed of professional scientists, hoped to make their colleagues better citizens, or "citizen scientists" (instead of "military scientists" or "industrial scientists"). These (citizen) scientists were called to take on their civic responsibilities and better serve the public interest—as determined by scientists. Today, the "citizen scientist" is no longer a professional scientist behaving like a responsible citizen, but a lay citizen who acts like a scientist, specifically in producing scientific knowledge (although the idea of the responsible scientists may still apply to the organizers of participatory projects). The legacy of the radical science movements of the 1960s and 1970s, such as Science for the People, the Union of Concerned Scientists, the British Society for Social Responsibility in Science, and many others (Sonnert and Holton, 2002), is only marginally connected to current modes of public participation where lay people contribute to the *production* of scientific knowledge, and far more with the configuration that emerged earlier (and continues to the present day), based on the involvement of the public in *deliberations* about science and technology that dominated the ideals of public participation in the 1980s and 1990s.

Indeed, in the 1980s, a number of "institutional experimentations" (Chilvers and Kearnes, 2015: 8), such as consensus conferences, participatory technology assessment, and science shops, aimed in Europe and the United States at making the voices of citizens heard in the formulation of national science policy or in making local technological choices (Petersen, 1984), and thus are best understood as a "deliberative regime" of public participation (Bucchi and Neresini, 2007). These initiatives—often grouped under the heading of "public engagement" as opposed to "public understanding"—are part of the broad "participatory turn" (Jasanoff, 2003), promoted by national and supranational governments (Saurugger, 2010) and international organizations such as the World Bank (World Bank, 1996). Following up on the ideals of earlier radical science movements, these forums aimed at identifying the public interest and setting the course of scientific research—conducted by scientists—towards serving them, a key element of what Helga Nowotny, Peter Scott, and Michael Gibbons (2002) have labeled the "Mode 2" of knowledge production. But this time, "the people" had an actual say in what it considered the public interest; however, it turned out, this occurred mostly at the very end of the research and development process. Abundant literature in science studies has described—and played a key role in crafting and promoting (Stilgoe et al., 2014)—the rise of these models of public engagement, especially upstream engagement, but has also exposed its numerous limitations (Jasanoff, 2013; Irwin, 2006; Felt et al., 2007).

It seems unclear if these institutional arrangements have restored public trust in science as their promoter had hoped, perhaps because they still implicitly envision the public through the "deficit model": the public lacks knowledge and expertise and is waiting to be enlightened (Wynne, 2006). One more troubling concern perhaps, is that these institutions could be considered less as a tool for helping the public participate in the governance of science than as a tool for governing the public's anxieties about science, while leaving the general course of scientific research unaltered (Pestre, 2011).

In the 1990s, the rise of public participation in scientific research and discourse about "citizen science" should be understood against the backdrop of this deliberative regime of public participation, focused on deliberation *about* science and technology. Specifically, participatory research, such as "citizen science," can be seen as a response to perceived shortcomings of the deliberative regimes and as yet another attempt at restoring a trustful relationship between science and the public. If this claim has any value, then it is crucial to critically examine shifts in science policy, in the European Commission for example, from "Science for Society" (FP7) to "Science *with* and for Society" (European Commission, 2016), which resulted in generous support for initiatives falling under the heading of "citizen science."

Obviously, this does not mean that the 1960s and 1970s, and especially the countercultural movements, were irrelevant for understanding the current rise of participatory research (McQuillan, 2014), only that the social movements conducted by *scientists* were perhaps not the most significant. Of far greater relevance, we argue, were the women's health movements, such as the Boston Women's Health Collective, which produced the newsprint *Our Bodies Our Selves* (Boston Women's Health Book Collective, 1971), and "popular epidemiology" which addressed the health issues of people living in toxic waste sites. In their attempts to "liberate" women from the patriarchal domination of medical professionals, self-help groups and feminist women's health centers were established in the 1970s to teach lay women how to *produce* biomedical knowledge about their own bodies through self-examination using cheap plastic speculums (today produced at home with 3D printers) (Morgen, 2002; Kline, 2010; Nelson, 2015; Mahr and Prüll, 2017). Most of this knowledge was mainly for individual use, but sometimes also served to challenge established biomedical knowledge, especially about fertility and pregnancy. Similarly, since the 1970s, communities living in environments perceived to be toxic, began to conduct epidemiological research to link the emergence of diseases, such as leukemia, with pollutants released in the environment (Brown et al., 1997; Brown, 2007). They too were producing new scientific knowledge, often challenging widespread consensus that the presence of pollutants (when acknowledged) was unrelated to the occurrence of diseases. These community efforts to challenge biomedical orthodoxy gained far more power in the unique circumstances of the AIDS crisis in the 1980s, when patient organizations, such as Act Up, succeeded in becoming legitimate—and unavoidable—partners in the production of biomedical knowledge (Epstein, 1996; Rabeharisoa and Callon, 2002). The heritage of the countercultural movements of the 1960s and 1970s for participatory research, and for science more generally (Kaiser and McCray, 2016), thus requires a serious reassessment.

Contextualizing the promises of "citizen science"

Among the various kinds of participatory research projects, those promoted under the banner of "citizen science" have produced a particularly dense promissory discourse. Three kinds of promises are made: a greater democratization of science, better scientific literacy, and new scientific breakthroughs. All three claims deserve critical scrutiny.

Democratizing Science?

The democratization thesis is certainly the brightest and at the same time the most opaque. It has been embraced almost unanimously by science policy bodies, promoters of "citizen science" projects, and the media. The European Commission put it unambiguously: "[Citizen science] allows for the democratization of science" (European Commission, 2015). The crowdsourcing platform Zooniverse put it more elegantly: "People Powered Research" (Zooniverse, 2016), and a guest blog of *Scientific American*, to make sure no one would miss the constitutional dimension of "citizen science," was astutely entitled: "Science of the People, by the People and for the People" (Cooper, 2015).

"Democracy" can refer to many things, but if one has to find a common element to most theories of democracy, it is the fact that some measure of power should be distributed among *all* citizens (Christiano, 2015). Thus, something becomes more democratic when more people, ideally everyone concerned, can take part. Countering the traditional view of science as an arcane activity and of scientists as a closed, elitist circle cut off from the community, the rhetoric of openness pervades public participation in science, and especially "citizen science." Organizers of "citizen science" projects stress repeatedly that "anyone can become a citizen scientist" (Gonforth, 2016).

But who does in fact participate? Are today's participants really "anyone"? Does their age, gender, ethnicity, class, and especially educational background, statistically represent that of "the people," a condition for public participation to fulfill its promises at democratizing science? The answer is that nobody really knows. Limited surveys of certain participatory projects seem to indicate that the participants are predominantly white, younger than average, middle class, and men (Curtis, 2015; Reed et al., 2013; Raddick et al., 2010), but little research has been done about the most important variable: their educational and professional background. If the goal of public participation is to expand the range of people involved in science, then it should reach out to people with little or no previous experience in science—although it cannot assume, as it usually does, that "anyone" desires to participate in scientific research (Haklay, 2013b). Taking the democratization argument seriously will thus require a more fine-grained analysis of the demographics of participation across the different kinds of participatory projects (distributed computing and do-it-yourself biology might not yield the same answers). A prosopography of today's contributors to participatory research will go a long way in assessing its contribution to the democratization of science.

A related issue concerns the actual size of the "crowd" participating in scientific research. Hyperbolic comments about massive crowds of "millions of participants" abound (Bonney et al., 2016), but such bold claims, and what is meant by "participant," have as yet received little scrutiny. In *Bowling Alone: The Collapse and Revival of American Community*, Robert D. Putnam notes that the millions of "members" joining environmental associations do not undermine his general claim about the decline in traditional communities because the meaning of "membership" has changed over time, becoming little more than the signing of a check rather than a personal and active involvement in an association (Putnam, 2001). Similarly, the participant who signs up for an online participatory project, but never contributes, should be distinguished from the one who spends most of her evenings and weekends in a DIY community laboratory. As in all other online communities, such as Wikipedia, there are great levels of inequality in the number of contributions by participants.

A way to contextualize the size of the participatory research "crowd" is to compare it to past examples where citizens were involved in the production of scientific knowledge (Vetter, 2011). In 1897, in Germany alone, around five thousand amateur ornithologists (individuals, their families, and local collectives) were mapping birds as members of a long-term biogeographic survey (Mahr, 2014). In the US, several thousand birders were contributing to the annual Christmas Bird Count since the first decade of the twentieth century (Barrow, 1998) and, starting in 1958, more than 750,000 volunteers were tracking artificial satellites in Operation Moonwatch to better understand their trajectories in the upper atmosphere (McCray, 2008). To carry any meaning, the numbers of individuals currently enrolled in participatory research should be brought into comparative perspective.

Educating Citizens in Science?

The second promise of participatory research, and especially in "citizen science" projects, revolves around science education and the need to raise scientific literacy, a major topic (together with participant motivation and data quality) in the literature about "citizen science" (Bonney et al., 2016; Herodotou et al., 2017). Empirical research on the learning outcomes of "citizen science" has documented improvements in content knowledge, but it remains inconclusive with regard to improving participants' understanding of the scientific process (Cronje et al., 2011; Masters et al., 2017), although future projects might well develop new methodologies to attain these goals. However, a more contextual understanding of these educational promises should highlight why increasing "scientific literacy" has become a task for "citizen science" to fulfill. Part of the answer stems from the changing meaning of "science literacy" since it was coined in the late 1950s, and the growing influence of international science learning assessments (DeBoer, 2011).

Immediately after the Second World War, science education became considered by governments as a critical tool, not just for moral and civic improvement, but for the training of the scientific workforce perceived to be essential for economic growth and national security in the Cold War (Rudolph, 2000). Discourses about the "knowledge economy" and "informational capitalism" in the 1980s renewed the desirability of training increasing amounts of "STEM workers" and made scientific literacy an essential part of modern citizenship (Kosmin et al., 2008). Although the shortage of "STEM workers" might no longer be true in the United States and other Western countries (Benderly, 2016), numerous educational policies remain in place to encourage careers in these fields, perhaps because of the belief that in a "knowledge economy," technological innovation will fuel economic growth. Moreover, many of today's global threats, from climate change to food (in)security, are perceived as having technological solutions, requiring the production of more entrepreneurial scientists; carbon capture and GMOs, for example. International science assessments, such the International Association for the Evaluation of Educational Achievement's Trends in International Mathematics and Science Study (TIMSS) (since 1995) or the OECD's Programme for International Student Assessment (PISA) (since 2000), have reinforced these trends and fueled a competition among nations towards attaining the highest score on these particular tests of "scientific literacy."

In these international assessments, as well as in numerous national educational policies, the meaning of "scientific literacy" has shifted from content knowledge to a broader understanding of the scientific process, the nature of science, and the nature of scientific inquiry (DeBoer, 2000). The failure of school laboratory instruction to increase students' understanding of the scientific process, a critique made as early as 1902, has made alternative pedagogical models, from out of school learning to informal learning, more attractive (DeBoer, 1991). By involving students, as well as adults, in authentic research projects, rather than "school science," organizers of "citizen science" projects could claim that participation would increase understanding of the research process, thereby aligning themselves with educational policies. Thus, understanding the rise of participatory research will require sustained attention to its framing as a solution to (international) educational challenges.

Producing New Science?

Finally, promoters of "citizen science" projects also promise new scientific breakthroughs made possible only by (massive) volunteer participation. The amount of work to be performed or the geographic reach of the observation to be collected is found to justify the enrollment of a large number of volunteers. The volunteers' individual lack of scientific expertise is compensated by the collective cognitive abilities that emerge from "wise crowds" (Surowiecki, 2005). Although participating in an online "citizen science" game like Foldit might seem like a solitary activity, in the words of one user, "chat windows, a wiki, duels and group play make Foldit into a social environment in which users learn from each other" (Perkel, 2008). A number of online participatory research projects, such as Foldit, EyeWire, or Galaxy Zoo, where volunteers analyze scientific data, have forcefully advertised how "citizen science" results in scientific publications in high profile journals, in which volunteers have occasionally been included as individual or collective ("Foldit Players" and "Eyewirers") co-authors (Horowitz et al., 2016; Kim et al., 2014). Economists have attempted to quantify the monetary benefits of using volunteers rather than professional researchers in producing these scientific contributions (Sauermann and Franzoni, 2015).

Nonetheless, understanding the contribution of volunteers to participatory research through the number of papers published or the economic value of volunteer labor might be somewhat of a narrow view. First, it is far from clear that all "citizen science" projects, even those directed by professional scientists, are aimed at solving problems deemed scientifically important by the scientific community. A number of the "scientific" problems given to volunteers by professional researchers would probably never have been carried out, regardless of the required resources, because they would have been considered of limited scientific and societal interest. In other words, this is not a zero-sum game, since the range of questions addressed by participatory research does not always overlap with that currently investigated by academic science. This does not undermine the value of participatory research, but it instead draws attention to the fact that public participation in research can also produce knowledge on parts of the natural and social world that have been largely unexamined scientifically. "Citizen science" has mainly been viewed as a way of assisting scientists in reaching their research goals, ignoring the possibility that participatory research could also expand what counts as the scientific worldview.

Second, public participation in research may not only change the territory of science but also the perspective on this territory. This is obviously true, according to any kind of standpoint theorist, because the inclusion of people from different social backgrounds, such as underprivileged minorities, with different personal experiences, such as patients with rare diseases, will result in the production of different knowledge, at least if they are given the power to frame research questions (Wylie and Sismondo, 2015). However, this might also be true for public participation in research where the "volunteers" have the least agency: crowdsourcing. Indeed, the most common argument for enrolling a wide spectrum of the public in crowdsourcing is the sheer number of simple tasks that need to be accomplished, such as classifying hundreds of thousands of images of galaxies. The rationale for involving the public, rather than automated methods, is that these tasks often involve, "intuition," "insight," and "pattern recognition," and thus cannot be easily performed by computers. As an article in *Scientific American* praising "citizen science" put it: "Humans retain an edge over computers when complex problems require intuition and leaps of insight rather than brute calculation" (Coren, 2011). Stories about amateurs who make exceptional contributions to research, for example, at solving highly complex 3D protein structures, highlight their unique set of cognitive, but also perceptive and affective qualities. In a piece published in *Nature,* Foldit player Scott "Boots" Zaccanelli, who works as "a buyer for a valve factory" but spends much of his spare time folding proteins on Foldit, is described as having reached sixth position in the game's rankings in part because of his personal abilities: "I can look at something and see that it's not right" (Hand, 2010: 687). Another player described her special "feel" for proteins (Boyle et al., 2011). Later, *Nature* simply called this "Science by intuition" (Marshall, 2012).

From the history of epistemology, it is rather striking that the mobilization of these abilities would become heralded as legitimate strategies for solving scientific problems, knowing that their *exclusion* was a key element in the formation of modern science, based on the ideal of objective, rational, and disinterested knowledge (Shapin, 1996; Dear, 2001; Daston and Galison, 2007). In this sense, citizen science sometimes seems to embrace a premodern (and postmodern) notion of knowledge, with the inclusion of "experiential knowledge" (Smith, 2006; Harkness, 2007) "embodied" knowledge (Lawrence and Shapin, 1998), and "situated knowledge" (Haraway, 1988; Longino, 1990; Fausto-Sterling, 1992). These epistemological commitments, if they turn out to provide viable alternatives to traditional scientific epistemologies, could have far-reaching consequences on the nature of the scientific knowledge produced and its relations to gender and power (for other epistemological critics of participatory science, Sieber and Haklay, 2015; Watson and Floridi, 2016)

Analyzing the epistemological values at play in current modes of public participation in research also illuminates their historical connections to earlier challenges to scientific authority. It is no historical accident that many of the successful challenges from lay people to scientific orthodoxy emerged from knowledge grounded in their own body or its immediate environment. The credibility of the knowledge claims made by women health activists in the 1970s, by AIDS patients in the 1980s, or by residents of toxic neighborhoods in the 1990s was based on their intimate experience of their own bodies and physical environments. Patients spoke on behalf of *their* bodies and residents on behalf of *their* environments (Epstein, 1996; Kohler, 2002; Brown, 1997). Because of this, their claims carried much epistemic weight, sometimes enough to overcome their professional marginality and challenge scientific consensus. Seen in this light, the contribution of participatory research could be far more significant than simply adding an army of unpaid volunteers to help in solving current scientific problems at a lower price. It could result in a different kind of science and a different kind of knowledge. If participatory research can transform *how* knowledge is being produced, at a deep epistemological level, then it could hold important potential for transforming *who* can produce legitimate knowledge and *what* we know about the natural world.

Conclusion

Taking stock of the rise of "citizen science" requires that we hold together an analysis of the discourse surrounding "citizen science" and a fine-grained examination of the practices that may only partially, and only provisionally, fall under its name. In other words, we should not let the label obscure, or entirely determine, the meaning of practices which, seen from the vantage point of the historian and sociologist of science, are significant in and of themselves. Of course, we need to understand where the label "citizen science" comes from, what strategic role it plays for the institutions and individuals who promote it, and how its performative power shapes and re-shapes actual practices of participation. However, we also need to move from "citizen science" to participatory research or even inquiry (Heron and Reason, 1997)—beyond the label, to the many ways in which members of the public have engaged and continue to engage in the production of scientific knowledge, and how they make sense of this engagement.

We have suggested that "citizen science" as a label emerged in the context of a shift, inside the participatory turn in science policy, from deliberation to production. "Citizen science" can indeed be seen as the next step of the participatory turn, one that has the potential to overcome the shortcomings of the deliberative regime by involving the public in the very production of science. "Citizen science" offers to turn anyone into a scientist, promising to produce new knowledge, educating the public and above all reconfiguring science from a closed to an open activity—in short, "democratizing" science. This context and these promises explain why so many typologies of "citizen science," both emic (by practitioners and promoters of "citizen science") and etic (by STS scholars), have focused on the degree or level of participation, implicitly measuring the extent to which the elitist barrier between scientists and the public has been undermined.

In paying close attention to the various practices and genealogies obscured by the uniformity of the label "citizen science," we have not attempted to shy away from its politics. Evaluating the promises of "citizen science" is, of course, necessary, for example by questioning and putting in perspective the nature and the size of the crowd of citizen scientists. But we believe that it is only through a better understanding of the epistemologies of participatory research projects that we can arrive at a better assessment of the politics of "citizen science." Our typology of five different epistemic practices—sensing, computing, analyzing, self-reporting, making—helps us see beyond the label and provides a useful entry point into the *longue durée* history of participatory research. If, as we have argued, "citizen science" signals the new challenges faced by the experimental sciences rather than the continuity of the tradition of the amateur naturalist, if "citizen science" has more to do with the countercultural movements of the 1960s and 1970s than with the radical science movements of that time, then it may have the potential to reconfigure science in ways that go deeper than the arithmetic of participation—in ways that are inextricably epistemological *and* political. Such a way is opened, for example, by the emphasis put on experiential or embodied knowledge (Strasser and Mahr, 2017), with tremendous consequences on not only the dominant scientific epistemology of the time, but also on the ways in which this epistemology is traditionally used to stabilize the social order and pacify social conflict.

We hope that our discussion can provide food for thought for more history of science- and STS-inspired studies of "citizen science." The current popularity of the term, in media and science policy discourses alike, should lead us to question what kind of society and what kind of science this particular mode of public participation in science is producing. Conceptualizing "citizen science" as a particular kind of relationship between science and the public (Nieto-Galan, 2016), specifically as a subset of public participation in research, opens up many possibilities for constructing meaningful historical narratives. Historical examples, when appropriately contextualized, can provide illuminating perspectives on how precise arrangements build and professional actors transform the relationships between knowledge and power. Long before the term "citizen science" was invented, proponents of "community-based (action) research" (or "participatory action research") inspired by the work of the Brazilian popular educator Paulo Freire and his successful *Pedagogy of the Oppressed* ([1968] 2000), sought to connect scholars and lay people to produce knowledge that could solve local problems (Gutberlet et al., 2014). Although they have often been mentioned, a more sustained attention to the history of "community-based research" and "participatory action research," a growing practice today, especially in public health, environmental, and social science research, could provide a welcome contextualization for studies of "citizen science" (Kindon et al., 2010).

Critical studies of "citizen science" could also benefit from the voluminous scholarship about these modes of participatory research (and their effects on the production of knowledge and the transformation of communities) to gain a better understanding of the politics of public participation in science, especially with regard to its function as counter-expertise (Ottinger, 2016). For example, philosopher Christopher Kullenberg, discussing air quality monitoring projects in Britain, has argued that "citizen science" could be a privileged tool of "resistance" by producing scientific facts that could then "travel without encountering the usual forms of opposition, thus creating a displacement of what can be contested" (Kullenberg, 2015: 61). Others, such as historian Sezin Topçu, exploring popular oppositions to nuclear technology in France, argued that citizens' efforts to produce "independent" counter-expertise largely failed to displace the debate's demarcation lines because the production of counter-expertise required the adoption of too many of science's epistemic norms, values, and framings, precisely those that had produced nuclear power as a "rational," "safe," and "cheap" technology (Topçu, 2013). The involvement of grassroots counter-expertise groups with governmental regulatory agencies can involve questionable trade-offs. As political scientist Gwen Ottinger aptly put it, "scientific legitimacy, however, may come at a cost: where social movement-based citizen scientists align themselves with expert practices for the sake of scientific legitimacy, their critiques of standard scientific practices are apt to get lost" (Ottinger, 2016: 99). The political effects of today's "citizen science" projects, such as those of the Public Laboratory, best known for its attempt to "tell a different story" of the 2010 Deepwater Horizon oil spill through participatory mapping (Public Lab, 2016), are largely unknown. Using a wider lens to empirically explore the consequences of various arrangements of experts and lay people in producing scientific knowledge—or redefining what counts as scientific knowledge—would go a long way in answering this question.

A related question concerns the extent to which the support for "citizen science" projects, mainly originating from science funding agencies and academic institutions, really aims at empowering lay people in relation to science. Aside from the legitimate question of how volunteer work should be rewarded, financially or otherwise, or whether they contribute to the social dumping of paid professionals and the "Uberizing" of research, one might ask if the enrolment of lay people in participatory research does not represent yet another effort at governing the critique of science, rather than producing citizens with a critical understanding of science and its role in society. The very notion of "citizen scientist," rather than "amateur scientist" for example, requires unpacking as it is unclear what it means to say that scientific literacy and scientific practice should become part of a fully developed citizenship. Is it about the production of a citizenry that embraces science and technology, a condition for liberal democracies to pursue the post-war alliance between science, technology, and the state? Is it about empowering a public to critically use the tools of science for solving some of its problems, while also resisting the hegemony of the scientific framing of others? Or is it about fostering scientific modes of reasoning among citizens, a condition for a robust deliberative democracy? Answering these questions will require sustained attention to the diversity of participatory practices, past and present, as well as how they transform knowledge, communities, and social order.

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Notes

1 These are topics we are currently addressing in a project "The Rise of Citizen Science: Rethinking Public Participation in Science," funded by and ERC/SNSF Consolidator Grant (BSCGI0_157787), headed by Bruno J. Strasser at the University of Geneva.

2 Throughout the article, *public participation in science* is used in the broadest sense to refer to any kind of participation, whether through education (e.g., going to a science museum), deliberation (e.g., joining a consensus conference), or production (e.g., classifying images of galaxies online). We use *public participation in research*, or just *participatory research*, as a subset of public participation in science, limited to instances in which the public participates in the *production* of scientific knowledge. We put "citizen science" between quotation marks to signal the fact that citizen science is above all a label that should be analysed at the level of discourse.

The Many Faces of Participation in Science: Literature Review and Proposal for a Three-Dimensional Framework

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Abstract:

Participatory and dialogic formats are the current trend in scientific communities across all disciplines, with movements such as public participation, citizen science, do-it-yourself-science, public science and many more. While these formats and the names and definitions given to them, are prospering and diversifying, there is no integrative tool to describe and compare different participatory approaches. In particular, several theories and models on participatory science governance and citizen science have been developed, but these theories are poorly linked. A review of existing typologies and frameworks in the field reveals that there is no single descriptive framework that covers the normative, epistemological and structural differences within the field while being open enough to describe the great variety of participatory research. We propose a three-dimensional framework, the participatory science cube, which bridges this gap. We discuss the framework's openness for different forms of participation as well as potential shortcomings and illustrate its application by analysing four case studies.

Keywords: citizen science, public participation, descriptive framework, public engagement with science and technology, participatory research, science governance

Participation in science as an established and currently-expanding field

Looking back at today's leading paradigms in science, future researchers might be tempted to speak of the 'citizen science turn'. Approaches aiming to including the public in scientific endeavours have been prospering across scientific disciplines leading to a multitude of participatory approaches, framed under divergent terms and utilising different structural and organizational methods of collaboration and dialogue: "It is now easier than ever for non-professionally trained people to participate in the governance, regulation, and translation of science, as well as in some of the core activities of science itself." (Prainsack, 2014: 149). Following the 'deliberative turn' in democratic theory and practice (Goodin, 2008), communication and dialogue became increasingly important for science governance and scientific policy advice. This led to the implementation of participatory practices for technology assessment, public dialogues on science and technology issues – especially on environmental aspects of these – and the development of various participatory methods from town-hall meetings to consensus conferences or citizen juries (Joss and Durant, 1995; Durant, 1999; Kasemir et al., 2003; Lengwiler, 2008).

While some disciplines and research fields can look back upon a long history of exchange and cooperation between professional and 'lay' scientists (Silvertown, 2009), the desire to open up science and research has become increasingly important even in fields where society has traditionally been in the role of the *studied object* (as in Political Science, Prainsack, 2014). Increasingly, the public is interested in changing roles and becoming a co-studying subject. Networks and associations in the field of citizen science are emerging and becoming increasingly professionalized, as, for example, the first international conference of the European Citizen Science Association in May 2016 illustrates. At the same time, influential funding institutions such as the German Federal Ministry of Education and Research are launching research grants explicitly for citizen science projects. In part, this paradigm shift towards open science may be the outcome of a bigger social trend. Scientists' unique status as objective keepers of truth and knowledge is being questioned in both public and social-science discourses and citizens are becoming more and more interested in getting a glimpse behind the scenes of academic life. Organizing research and science in a more open, democratic and participatory fashion seems to be an appropriate answer to the phenomena described as "science alienation" (Wilsdon and Willis, 2004; Hagendijk and Irwin, 2006; Stirling, 2008). Apart from citizen science there are various approaches to open science up to the interested public and, in many cases, for collaboration with citizens. Within this movement both the concepts, and the denominations they are given, vary. Participatory science, do-it-yourself-science, participatory health research and public history are just some of the terms used to describe approaches of public inclusion in different scientific fields.

While the plurality of formats, and the names given to them, is stunning, most participatory projects in science and research can be traced back to two main paradigms: the public participates either in a *dialogue* about science (governance) or in *doing science* in its diverse forms. We use the term *dialogic formats* to cover all types of consultations and public discussions, e.g. about nuclear waste management or about potential benefits and risks of genetically modified organisms. The *doing-science-together approaches* invite citizens to take part in the process of generating knowledge. Classic examples of co-research projects are those aimed at monitoring biodiversity (e.g. the Christmas Bird Count, see Silvertown, 2009), but co-researching is also very common outside the environmental and biological sciences.

Although science participation through dialogue and through co-research displays similarities, academic discourses regarding the two approaches have been taken place separately. This holds especially true for typologies and frameworks describing this diverse field. While a focussed framework can better account specific details and enhance distinction within a subset of participatory formats, the lack of a comprehensive basis for comparison and discussion keeps the two discourses in their respective silos and often prevents exchange and mutual learning. In this paper, we aim to bring the two academic discourses together and develop a descriptive framework that covers both dialogic formats and co-research.

The academic discussion both on dialogic as on co-researching projects often takes a normative course, raising questions about the quality of findings or the quality of the process. Many existing frameworks intend to structure and simplify the evaluation of participatory science projects by proposing (assessment) criteria individual projects should meet (Abelson et al., 2003; Lynam et al., 2007; Tippett et al., 2007). However, the implementation of the frequently normative criteria remains unclear: What does 'inclusiveness' in participant selection or 'readability' of the provided information mean? How should these criteria be measured? Unlike many of the normative approaches, we seek to develop a model that describes participatory formats and their similarities and differences.

In developing our model, we first conducted a systematic review of the literature produced in recent years on two aspects of science participation: conceptual frameworks and typologies in science governance and conceptual frameworks in citizen science and other participatory research approaches. We find that there is no genuinely descriptive model that integrates the broad variety of approaches in the field. Therefore, we draw on Archon Fung's (2006) democracy cube, a model for participatory democracy, and adapt it to apply to participatory and dialogic science initiatives of all kinds. In order to illustrate the variety of instruments, projects and mechanisms that the cube helps to describe and frame, we present four examples of participatory science projects and place them in the cube. Finally, we discuss the strengths and limitations of the framework and invite a broader scholarly debate on the cube and other typologies.

Current models and typologies for participation in science

Academic discourse on participation builds on research on participation and deliberation in political science and democratic theory, addressing the roles of the various actors within decision-making processes. When this role-based theory is applied to participation in science governance, scientists are attributed the responsibility to "support (self-)enlightenment of citizens by acting as co-learners" and the role of citizens is to "articulate and develop [their] own interests" and "participate in all stages of political process" (Biegelbauer and Hansen, 2011: 591). The frameworks on dialogue and public participation presented in the following section reflect and build on this aspect. Citizen science goes beyond deliberative participation and considers "citizen knowledge and citizen participation in scientific debate" (Irwin, 1995: 111). Accordingly, the existing frameworks for citizen science reflect this focus on (scientific) knowledge generation and build on the models of research processes. In the following, we will present a review of the essential typologies and frameworks of both fields.

Models for dialogue and public participation in science governance

In the field of dialogic participation, there are numerous typologies and models. Mark S. Reed (2008) gives an exemplary overview of the approaches applicable in environmental management. He includes descriptive, normative, and evaluative typologies without differentiating between them, so that typologies that serve different purposes (describing, assessing and evaluating) are considered as equivalents. In the following, we want to discuss the most important approaches in categorizing public dialogue and participation separately, so that their specific focal points become clear.

The classic: Sherry Arnstein's ladder of participation and similar approaches

Before thinking about participation in science, it appears worthwhile to revisit literature on models for public dialogue and participation. Probably one of the most frequently cited publications in the field is Sherry Arnstein's (1969) ladder of citizen participation, a typology for mechanisms of politically involving citizens. The ladder "which is designed to be provocative" (Arnstein, 1969: 216) is constituted by eight rungs and describes the degree of power control delegated to the citizens involved (see Table 1). While all forms of manipulation and therapy count as *nonparticipation*; informing, consulting and placating citizens constitute *different forms of tokenism*. Real *citizen power* is achieved by partnership, even more by delegated power and in its most intense form by citizen control. Even though Arnstein's ladder is, in the strict sense, an instrument for labelling *political* participation processes, we summarize the model here because it has inspired several typologies that follow her normative distinction of good and bad forms of public participation (Chung and Lounsbury, 2006; Wright et al., 2010) – not only in the political sciences but also in the field of participation in *science*.

In a similar vein and as shown in Table 1, Rowe and Frewer (2005: 263) differentiate between three different types of public engagement, which differ in the direction the information flows. The first type, *public communication*, incorporates all mechanisms where the initiating agency gives information to the public. The flow of information therefore leads from the sponsors of the mechanism to the public without a formal need for public feedback. In the second type, *public consultation*, the flow of information goes in the other direction and the public provides information to the initiators of the participation process. While the first two types of public engagement do not include a formal dialogue between the conveners of the process and the participants, the third type – *public participation* – implies an exchange of information between both sponsors and public. In order to further describe specific types (and potentially evaluate them scientifically) Rowe and Frewer (2005: 265) broaden the three types of engagement by including six characteristics with binary options. They distinguish participation mechanisms further by (1) whether the selection of participants is controlled, (2) whether they facilitate information, (3) whether participants can contribute information, with or without limits, (4) whether the information provided in the process is set or flexible, (5) whether communication occurs face-to-face or not and (6) whether the aggregation of participant information is facilitated in a structured or in a non-structured way. Based on the first typology of the information flow and the six characteristics of the participation mechanism, the authors identify four communication types, six consultation types and four participation types. Their typology seeks to enable a better description of public engagement within science and technology and beyond.[1]

Instead of closed categories: a descriptive map of science participation

While the two frameworks by Arnstein (1969) and Rowe and Frewer (2005) establish categorical types of dialogue and participation, Bucchi and Neresini (2008) offer a different approach by developing a *descriptive* framework for public participation in science. It takes the form of a two-dimensional coordinate plane where the axes plot continuous variables between two extremes

Table 1: Overview on frameworks for dialogue and public participation.

Author(s)	Categories of typology	Sub-categories
Arnstein (1969): Ladder of Citizen Participation	nonparticipation	manipulation / therapy
	degrees of tokenism	informing / consultation / placation
	degrees of citizen power	partnership
		delegated power
		citizen control
Rowe and Frewer (2005): Typology of public engagement mechanisms	public communication / public consultation / public participation	control of participation selection / facilitation of information / limitation of information contribution by participants / flexibility of the information provided in the process / mode of communication; aggregation of participant information
Bucchi and Neresini (2008): map of public participation in science and technology	intensity of participation in the knowledge construction process	high / low
	degree of spontaneity of public participation	sponsored / spontaneous

instead of concrete values. The first axis captures the intensity of participation in knowledge construction between the two poles of high and low intensity. Similarly, the second axis depicts whether the respective participation mechanism occurs in a sponsored or a spontaneous fashion. The intensity of public participation is ranked in the middle between intensive and basic depths of involvement.

The commonality between the reviewed frameworks for dialogue and public participation is the core issue of inclusion in the normative process of decision-making. The operationalized categories of the frameworks vary from more theoretical considerations of degrees of power-sharing and normative influence on the one side, to more practical aspects for the conduct of participatory processes on the other side.

Models for citizen science

The core issue of citizen science is the participation of non-regular scientists in the process of knowledge generation. The various typologies for citizen science differ in their normative perspectives on the role and function of citizen science and the terminology they use. As summarized by Riesch and Potter (2013: 107-108) citizen science "is a contested term with multiple origins, having been coined independently in the mid-1990s by Rick Bonney in the US (see Bonney et al., 2009) to refer to public-participation engagement and science communication projects, and in the UK by Alan Irwin (1995) to refer to his developing concepts of scientific citizenship which foregrounds the necessity of opening up science and science policy processes to the public." In this paper, we will apply a broad and more descriptive understanding of citizen science as the inclusion of non-traditional, non-institutionalized and non-professional researchers in the process of knowledge generation, including research processes conducted without institutionalized scientists at all (Bonn et al., 2016). The existing models for citizen science can be grouped into three broad categories, described in the following section.

Participation in the different stages of a scientific process

A common approach is to categorize citizen science according to its openness along the prototypical steps of a scientific process from formulating research questions to the actual conduct of research and the subsequent analysis. During the Citizen Science Toolkit Conference, Candie Wilderman (2007) presented three models for what she called community science. The three models are based on the questions "Who is it that is actually defining the problem? That is, who is setting the agenda for the research? Who is it that is actually designing the study? Who is that is collecting the samples? Who is it that is analysing the samples? Who interprets the data?" (Wilderman, 2007; see Table 2). These questions represent the steps of a classical scientific process. Depending on the responsibilities for these steps, the models are sorted with an increasing degree of participation by the community in the research process. The 'community consulting model' follows the idea of 'science shops' originating in the Netherlands in the 1970s (Leydesdorff and Ward, 2005). Under this model, the community defines a problem and research task, while the research itself is conducted by professional scientists. The "community workers model" encompasses various collaboratory settings, from public data-collection, through to a collaborative analysis. The 'community-based participatory research model' describes projects where all tasks are conducted by the community, equivalent to participatory-action research approaches (Whyte, 1991).

A similar model describes types of participation in the adaptive management of natural resources informed by (participatory) research (Cooper et al., 2007). The model includes Wilderman's three types with the same specification. Additionally, two more models – 'adaptive citizen science research' and 'adaptive co-management research' – include a feedback loop, in which the results are presented and discussed with the public (either on an individual level or in a broad setting) to adaptively influence data-collection during the process.

In 2009, an expert group prepared a report for the Center for Advancement of Informal Science Education (CAISE) on public participation in scientific research including a typology (Bonney et al., 2009). The typology is also built on the steps of a scientific process, from problem definition to data collection, analysis and interpretation of the results. They define three basic models for public participation in scientific research, with increasing involvement of the public just like a participation ladder: *Contributory* projects (designed by scientists with participation being primarily the collection of data), *collaborative* projects (also designed by scientists, but with more in-depth participation of the public, for example contributions to data analysis or discussions about interpretation) and *co-created* projects (where the public participates in all steps from the beginning to the end; for an overview see Bonney et al., 2009: 17). The authors explicitly state, that they "have deliberately excluded public engagement in science (PES) activities that involve members of the public influencing public policy as opposed to participating directly in research" (Bonney et al., 2009: 19).

In 2012 a group of researchers, many of whom were also authors of the CAISE report, presented an extended version of the typology with five components (Shirk et al., 2012; see Table 2). In addition to the three models (contributory, collaborative and co-created projects) they present two more models which fall outside of the hierarchical order of the other three with their increasing inclusion of the lay public. The first, contractual projects, "where communities ask professional researchers to conduct a specific scientific investigation and report on the results" (Shirk et al., 2012) shows similarities to normative policy-influencing participation, but with a concrete project focus. The second, collegial contributions "where non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals" (Shirk et al., 2012), summarizes projects within the hacker and maker community without the participation of institutionalized scientists.

Observations of participation as it occurs in the wild

A second group of models follows an approach oriented towards the practical implementation of citizen science projects and heuristic observations. Andrea Wiggins and Kevin Crowston (2011) review the earlier typologies based on theoretical research steps and suggest an "empirically-grounded typology of citizen science projects" as an additional approach. They examined a sample of existing citizen science projects and coded them according to 80 criteria which they analysed for common characteristics. As a result they present five different types of projects, differing in project goals and also the role of on-site participation (as opposed to online participation): Action, Conservation, Investigation, Virtual, and Education. This heuristic approach presents a practical perspective on existing citizen science projects from diverse categories. They refined their approach with a cluster analysis based on questionnaire responses from existing citizen science projects. Thus the clusters are built on the empirical data and do not reflect theoretical or systematic considerations. The two main categories considered for the definition of the clusters were participants' tasks within citizen science projects as well as the stated goals of the project (Wiggins and Crowston, 2012).

Focussing on participation in environmental science, Janis L. Dickinson and Rick Bonney (2012) present a framework for citizen science projects with four major axes, which is also based on a heuristic approach looking at practical aspects of project implementation. They describe the axes as follows, "(1) initiator of the project, professional scientists or the public; (2) scale and duration of the project, whether local or global and short term or long term; (3) types of questions being asked, ranging from pattern detection to experimental hypothesis testing; and (4) goals, which include research, education, and behavioural change (e.g. towards environmental stewardship)" (Dickinson and Bonney, 2012: 6).

Barbara Prainsack (2014) proposes a typology for citizen science based on six main characteristics that address different structural aspects of the respective project, namely its (1) coordination (agenda setting; decisions about results, intellectual property etc.), (2) participation forms and processes (profile of participants, resources required to participate etc.), (3) relationships toward communities (relation to existing communities, facilitation of building new communities etc.), (4) evaluation (definition of 'success', handling of the results), (5) openness (access to data and findings; acknowledgment of participants' contribution etc.) and (6) entrepreneurship (funding, economic use of the results, roles in the project). To illustrate the meaning of each feature she proposes related questions, for example, who decides on the evaluation criteria? Do participants take part in establishing the core datasets? What are the prerequisites for joining the project?

Chiara Franzoni and Henry Sauermann (2013) present a framework for what they refer to as crowd science, which differs in approach and focus from the other frameworks discussed here. It distinguishes on one axis the openness of project participation and on the other axis the disclosure of intermediate inputs such as data or algorithms. The two axes come together to form a four-quadrant diagram. The framework is limited in its scope and does not include further-reaching forms of participation and empowerment. Also, the tailoring of the framework and the chosen examples show a clear emphasis on online-collaborations.

Participation within a normative hierarchy

The third group of models focuses on the normative dimension of openness and participation. Muki Haklay (2013) describes a framework similar to the various frameworks presented earlier which consider participation in the different steps of the scientific process. He proposes four levels of participation: level 1: crowdsourcing, level 2: distributed Intelligence, level 3: participatory science, level 4: extreme citizen science. With this categorization under explicit hierarchical labels, he draws on the concept of the participation ladder, with a normative reasoning, "the participation hierarchy can be seen to be moving from a 'business as usual' scientific epistemology at the bottom to a more egalitarian approach to scientific knowledge production at the top" (Haklay, 2013: 118).

This ranking of participation is reduced to a normative-laden binary framework presented by Finke and Laszlo (2014) with the two main categories "citizen science light" for activities, where citizens only contribute by collecting data or assisting in simpler tasks, and "citizen science proper" where citizens are equal partners with professional scientists in a joint project.

Our review of models of citizen science shows that the common issue of including non-professional participants in the process of knowledge generation is the defining element of distinction in some typologies, while others consider more practical aspects for differentiation. The focus of the citizen science frameworks varies between theoretical and normative considerations, ranging from the degree of influence on the epistemic process, to the more practical aspects of the implementation of citizen science projects.

Table 2: Overview of frameworks for citizen science projects.

Author(s)	Categories of typology
Wilderman (2007) * Cooper et al. (2007) †	community consulting model †* / community workers model †* / community-based participatory research model †* / adaptive citizen science research † / adaptive co-management research †
Bonney et al. (2009) * Shirk et al. (2012) †	contributory projects †* / collaborative projects †* / co-created projects †* / contractual projects † / collegial contributions †
Wiggins and Crowston (2011)	action / conservation / investigation / virtual / education
Dickinson and Bonney (2012)	initiator of the project / scale and duration of the project / types of questions being asked / goals
Prainsack (2014)	coordination / participation / community / evaluation / openness / entrepreneurship
Franzoni and Sauermann (2013)	project participation / disclosure of intermediate inputs
Haklay (2013)	crowdsourcing / distributed intelligence / participatory science / extreme citizen science
Finke and Laszlo (2014)	citizen science light / citizen science proper

Bringing the two worlds together?

The academic discourses on frameworks for participatory science governance and citizen science with its different connotations, including fields like participatory action research, have so far been mostly divided into the siloes of their respective academic tradition. Furthermore, a joint discussion is hindered by delimiting terms and definitions and normative-laden models which disregard a wider perspective.

There are some analyses of participatory science which include aspects of discursive participation and contribution to the research process. One example is the case of "contractual projects" included in the framework (Shirk et al., 2012), with communities requesting specific research projects, often focussed on a local issue affecting the community and relevant for decision-making. Another is the Green Paper "Citizen Science Strategy 2020 for Germany", discussing "Incorporating Citizen Science Results into Decision-Making Processes" (Bonn et al., 2016: 10) or the report from a workshop focussing on participation and citizen science from the process leading to the strategy (Pettibone et al., 2016). Wehling (2012) distinguishes "invited" participation (e.g. stakeholder dialogues) and "uninvited" participation (e.g. community activism) from a technology assessment perspective. Haklay (2013) cites Arnsteins (1969) participation ladder when developing their citizen science model, but only briefly discusses the structural connections and differences between citizen science typologies. Sabine Maasen and Sascha Dickel (2016: 236) refer to both aspects in the "Handbuch Wissenschaftspolitik" with a consideration of "normative questions – empirical answers".

Jason Corburn (2005) refers to the collaboration between local and academic knowledge for problem-solving as 'street science'. His concept includes participatory knowledge-generation as well as decision-making and builds on the understanding of participatory action research and the co-production model of expertise, where not only the methods of research but also the definitions and framing of the problem are decided on via a participatory approach (Corburn, 2015: 19).

A publication exploring the 'public engagement rhetoric' in the field of biomedical research defines three modes of public participation in science: participation, engagement and involvement (Woolley et al., 2016). In their model, *participation* "suggests an active, intentional role, but can also describe quite passive forms of inclusion", *engagement* means that "members of the public can be more or less engaged in scientific studies, depending on the extent to which scientists seek to communicate their plans and solicit the public's cooperation in collecting data" and *involvement* implies that "members of the public have an active role in in the planning and conduct of the research itself, even to the level of choosing the scientific questions to be addressed" (Woolley et al., 2016: 2). The authors combine the three terms into an overlapping Venn-diagram, where e.g. pure participation means crowdsourcing or the overlap of participation and engagement "classical citizen science" (Woolley et al., 2016: 3). However, the definition of the framework, along with the chosen terminology, seems to be ad-hoc and does not reflect the existing academic discussions of the terms and their meanings. Also, the framework seems to be inconsistent, for example 'public deliberation' is not seen as being part of 'involvement' although it would fulfil the definition of "having an active role in in the planning (...) of the research" (Woolley et al., 2016: 3).

Drawing a broader and more conclusive picture building on the existing frameworks, Dick Kasperowski has described the field of citizen science as consisting of three forms, including governance discourse and research contribution: "Citizen science describes at least three things: 1) citizen science as [a] mere research method, which aims at producing scientific results. 2) citizen science as public participation, with the aim of creating legitimation for science and science policy within society 3) citizen science as citizen mobilization, with the aim of exercising legal or political influence on certain issues" (translated from Herb, 2016; see also Kasperowski and Brounéus, 2016).

While these approaches have started a push towards a common framework for participation in science and presented some components of it, they have not yet presented a comprehensive and systematic typology of the field.

Proposal for a three-dimensional framework: the participatory science cube

The various models and frameworks for participation in science presented above have in each case been developed from the perspective, and within the tradition and context of, a *specific academic discipline*. While some models span across more than one field and consider multi-disciplinary aspects, most focus on specific aspects

Despite their differences, all the described models are built around a one-dimensional scale and a linear hierarchy of categories. While this does allow for a detailed analysis, albeit from a rather narrow angle of view, it hinders a holistic consideration of all forms of dialogue and participation as different manifestations of participation in science. To overcome this hurdle and consider the many established forms of participation and the diversity of approaches, a framework has to be built with more than just one dimension.

In this vein, Susan Stocklmayer (2013) developed a three-dimensional model for science communication that she named the "science communication field". It differentiates between the sender of the communicative message (axis 1), the receiver of the message (axis 2) and the intended outcome of the respective communicative act (axis 3 with three categories: one-way information transfer, knowledge sharing or knowledge building). The *science communication field* demonstrates the usefulness of three-dimensional models; but while its focus on communication and the involved entities (sender/receiver) is useful within science communication, it is too specific for the diverse forms of science participation. Stocklmayer's (2013) model shows that the connection of three dimensions into the analysis of a complex communicative process is helpful in modelling and developing methods to analyse a rapidly developing sphere at the interface between science and society. Nonetheless, her communicative approach meets a demand that is not ours, as we focus on *participation in* science rather than *communication about* it. Also, the very granular design of this model makes it poorly suited as a broad unifying model of participation in science.

The idea of a multi-dimensional framework with a specific focus on *participation* was proposed by Archon Fung in 2006. His 'democracy cube' describes deliberative participation in governance, but with a generalization and re-focussing on participation in science. The framework can be expanded to develop a three-dimensional 'participatory science cube', which is able to locate the broad variety of participatory formats – from science policy dialogues to citizen science projects – in a joint space. The established categories conceived in Fung's model serve as basis for the axes of the participatory science cube.

The idea of bringing together concepts of political participation and participation in science is not new and has been taken up by concepts such as scientific citizenship (Irwin, 2001): "[scientific citizenship] implies not only that scientific knowledge is important for citizenship in contemporary society but also that citizens can lay a legitimate claim to accountability in scientific research. As such, the notion can be perceived as a normative ideal concerning the appropriate form of democratic governance in a society that has become increasingly dependent on scientific knowledge" (Horst, 2007: 151). Participatory governance and participatory science follow similar goals: opening up systems to new groups with previously rather closed mechanisms (decision-making on the one hand and scientific knowledge production on the other hand). With this paper, we want to bring these two discourses on participation together: we have started with a review of both aspects in the previous sections, we discuss the democracy cube in the next section and, finally, propose a new framework for science participation based on Fung's democracy cube.

Origin: the "democracy cube" by Archon Fung

Archon Fung's framework for describing the variety of possibilities for political top-down participation comprises three dimensions that frame (1) who participates, (2) in which ways the participants communicate and decide and (3) how these discourses and decisions are integrated in the political context.

Fung describes three main factors that make a description of participatory instruments necessary. Firstly, different forms and instruments of political participation exist in modern societies. They offer different modes and depths of involvement and address different institutions. However, it remains unclear how to compare them, as "there is no canonical form" of direct political participation. While normative categories have been proposed, there is a lack of descriptive tools, which the democracy cube intends to remedy. Secondly, political values, such as equality of participants or a respectful dialogue process, are hard to quantify and even harder to compare on a large scale. Therefore, it is more useful to describe the mechanisms of participation rather than attempting a normative approach based on abstract values. Thirdly, participatory instruments are very often tightly intertwined with other forms of political decision-making in representative structures and bodies. Analytically, it is difficult to draw the line between public participation, representation and administration. The democracy cube is an inclusive model that can describe mixed forms of political participation and even political decision-making without citizen participation at all.

In short, the democracy cube integrates three dimensions and creates a space where the different kinds of participatory mechanisms in politics can be placed. It defines democratic participation based on its method of participant selection, its modes of communication and design, and the authority and power delegated to the participants. In the following, we briefly summarize the three axes and their main categories.

Fung's three dimensions: who participates? How? Who decides?

The first dimension – Participation Selection Methods (axis #1) – asks who is eligible to participate and differentiates between five common participant selection mechanisms. The most open approach consists of *inviting all those who*

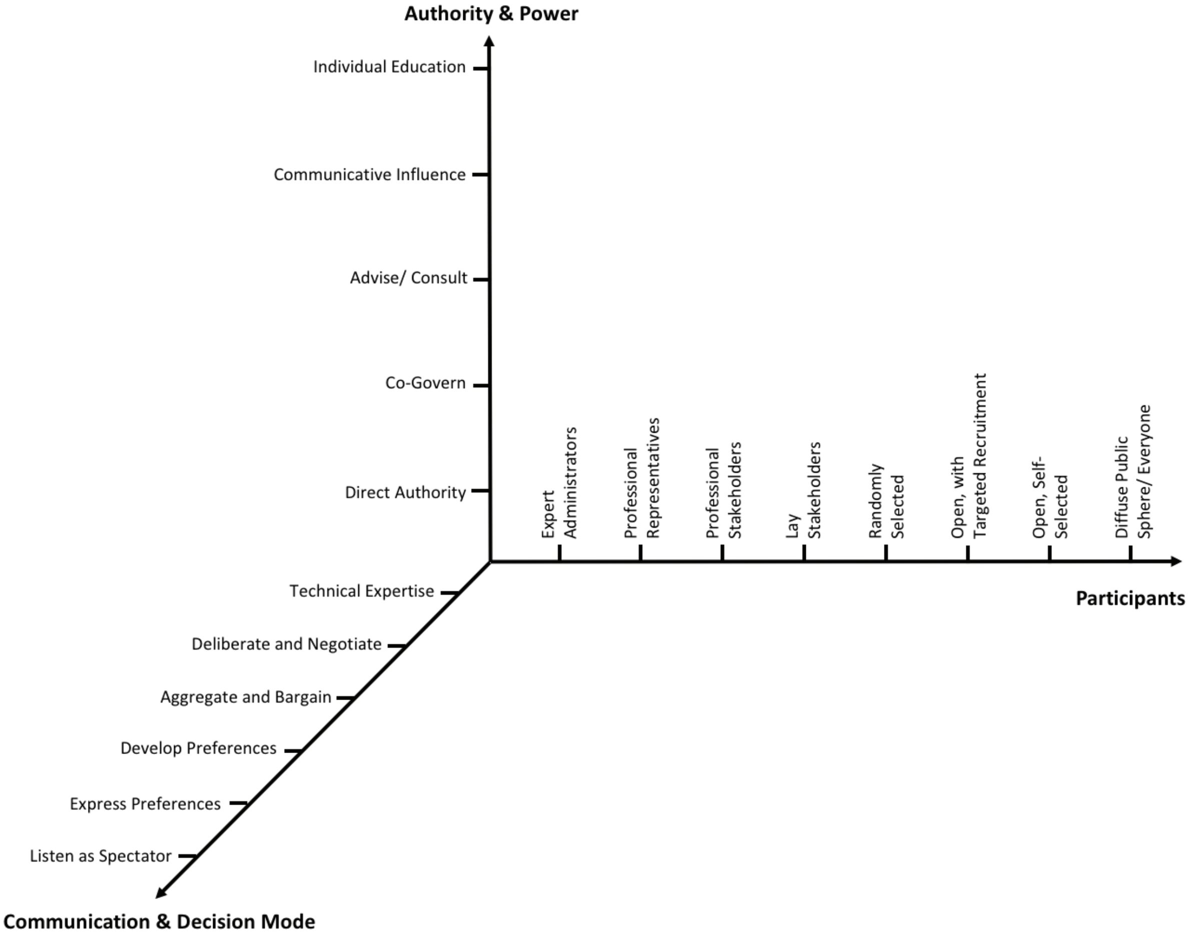

Figure 1: The democracy cube as introduced by Archon Fung (2006).

wish to participate so that the participants are a self-selected sample of the general population. Altogether, eight methods of addressing participants are located along the axis according to their degree of inclusiveness.

The second dimension – Communication and Decision (axis #2) – examines the question of how the public participates and presents three ways of communicating (listening as spectator, expressing preferences, developing preferences) and three forms of decision-making (aggregating and bargaining, deliberating and negotiating, deploying technical expertise).

The third dimension – Authority and Power (axis #3) – frames the question: how much power does the specific mechanism of participation delegate to the participants? Do the citizens have a say in the process and decision-taking or is their primary benefit personal (through learning, social ties etc.) The power and authority dimension of Fung's democracy cube covers five types of political influence, from processes where participants benefit mostly personally to mechanisms where they exert direct authority.

Participation in three dimensions

The three dimensions combined constitute a descriptive three-dimensional space – the democracy cube (see figure 1) – that facilitates describing and comparing different participatory mechanisms according to who participates, how decisions are taken and by whom.

Adapted model: the 'Participatory Science Cube'

The axes of Archon Fung's (2006) democracy cube represent the central dimensions of participatory governance. In order to build a joint framework for deliberation and dialogue on science and science policy together with participation in the scientific process of knowledge generation, it is necessary to consider the underlying issues which impact on the actors.

By including all kinds of participation in science we follow the interpretation of Trench (2006, 2008) and Stocklmayer (2013), that participation in science is a *continuum* that moves between the two poles of (1) one way communication (including all forms of promotion of science) and of (2) two-way communication (including all scientific activities of building knowledge together, e.g. citizen science). In addition, a broad notion of participatory science might inspire science communicators (who focus on one-way communication) to become more open to dialogic or even collaborative formats.

Dialogues are carried out to address the question of *what ought to be done* (and may result in a policy, decision, recommendation, etc.). Therefore, dialogues and deliberative participation approaches open up the *normative dimension* of science. Rather than scientists[2] alone deciding on the course and conditions for their research, the public or its representatives are included in the decision-making process. The degree of participation varies, as described in the various models for dialogue processes, summarized above. Meanwhile, the conduct of the research within the agreed rules and guidelines remains in the hand of the scientists.

In contrast to dialogues, citizen science projects address questions of *what and how we know*: the process of knowledge generation and validation is opened up towards 'lay' people. Depending on the project, scientists may seek citizens' support for research tasks, their specialized (e.g. local or practically informed) knowledge or their collaboration on data analysis and interpretation. Therefore, the core issue for participation in citizen science is the *epistemic contribution*. The range of participatory possibilities is described in the various frameworks for citizen science.

Looking at Archon Fung's (2006) 'democracy cube' which is designed to describe governance in general, it becomes clear that the third dimension for a participatory science framework should also be led by the question of who participates. The participants may range from stakeholders with specialized knowledge and/or legitimacy from societal sub-groups like non-governmental organizations to the general public.

Putting these aspects together, Archon Fung's 'democracy' cube can be transformed into a 'participatory science cube', incorporating dimensions derived from the previously discussed models and describing the various modes of participation in science using a single three-dimensional framework: the first axis of the cube is the normative focus (close to Fung's dimension of "Authority & Power" which is also a normative component), the second axis is the epistemic focus (showing which aspects the knowledge process citizens contribute to) and the third axis is the public (out-)reach (which is, in principle, equivalent to Fung's "participants" axis). This proposed structure is also partly reflected in Jason Corburn's (2005) considerations, when he discusses the benefits of local knowledge for research as well as policy-making. He proposes four categories for participatory benefits for decision-making, one being epistemology as also proposed here. The other three categories (procedural democracy, effectiveness, distributive justice) represent a more fine-grained view of normative aspects, including the reach of participatory processes encompassed in the aspect of procedural democracy (Corburn, 2005: 71).

All three axes describe a continuum between primary actors being scientists at one end and the public at the other end. The positioning of a participatory science project along these axes describes the relative balance and focus of the components between a traditional institutional science project and an open public project. The further out a project is located, the more responsibility and empowerment lies with citizens for that dimension. The subdivision of the axes into distinct categories primarily serves as point of orientation, as the boundaries between the various steps can be blurry and categories may partially overlap for certain projects.

Dimension 1: Normative Focus

The axis describes the degree to which the public is included in decision-making on science and technology governance, for example in priority

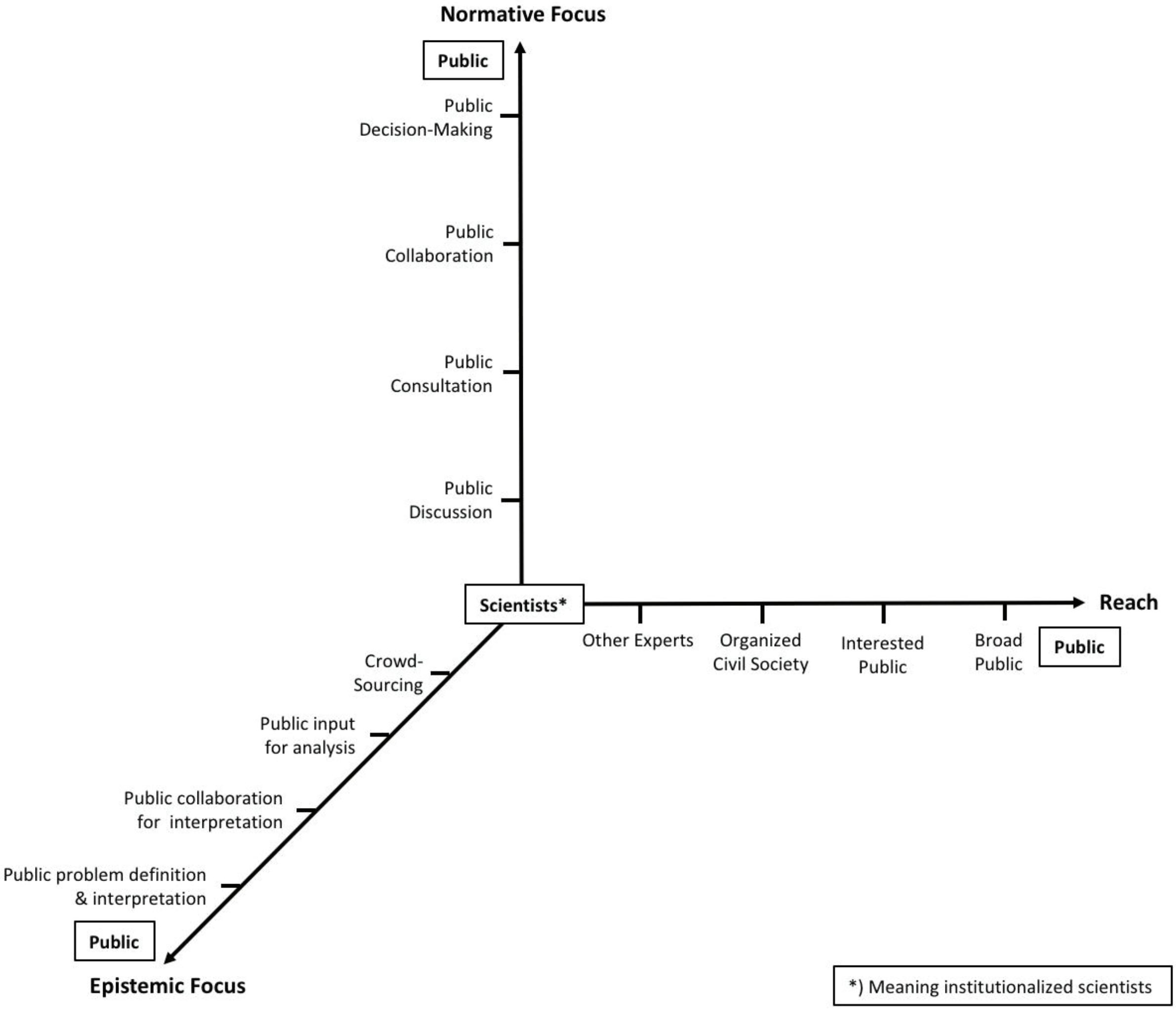

Figure 2: The participatory science cube.

setting, funding allocations, legal restrictions on, or support for, science and technology; or assessment of scientific policy advice. This category considers questions of values and norms as well as questions of preferences and interests. The proposed subdivisions for the axis are derived from the common elements of deliberative participation frameworks described in section "Models for dialogue and public participation in science governance" – from public discussion, to consultation and collaboration, up to public decision-making.

Dimension 2: Epistemic Focus

The axis depicts the degree to which actors other than institutionalized scientists are included into the epistemic process of knowledge generation. The more the public is involved, the more epistemic weight is attributed to them in the research endeavour. In contrast to the normative axis, the epistemic focus considers a specific issue at stake. Therefore, an increasing public contribution, up to the stage of problem definition by the public, means an increased normative say within the project and the limited set of project participants. The overall normative focus on research in general, or even the field of science the project originates from, is not affected. The suggested elements dividing this axis are derived from the common elements of frameworks for citizen science in section "Models for Citizen Science", which are built around the scientific process, from taking over simple tasks in the form of crowdsourcing, to a more in-depth public input, to public collaboration on the interpretation of data, to involving the public in problem definition or the public interpreting data independently.

Dimension 3: Reach

This axis represents the reach of a project beyond institutionalized scientists. The proposed divisions of the axis are modelled on a simplified version of Archon Fung's "participants" axis. They range from experts from other fields (e.g. relevant experts from industry, civil society organizations, administration or politics as well as scientific experts from other disciplines from the original project), to organized civil society associations, the interested public and the general public. The categories are meant to cover the field as broadly and inclusively as possible. The definition of the total public that could be reached by a given project is debateable. It could be a regional community for regional issues through to national populations or even the whole world population. This aspect needs to be addressed when the participatory science cube framework is applied. Furthermore, one needs to take into consideration the design and intended reach of the project versus the reach actually achieved. In the discussion of a case study, it should be clarified whether a low turnout is an inherent issue in the design and implementation of a project (and thus should affect the classification of the project) or based on individual circumstances or the implementation of a certain instance of the project.

Discussion

The participatory science cube provides a common space to visualize and discuss various participatory approaches. The cube constitutes a descriptive framework on a macro level and is intended to provide a basic typology. The participatory science cube aims at reflecting the heterogeneity in the field of science participation while at the same time offering categories to structure the diversity. It allows users to compare and distinguish participatory approaches across the wide spectrum of epistemic and normative influence on the conduct of scientific research. The participatory science cube makes it possible to draw a broad and comprehensive picture of the opening up of science and the development of new forms of collaboration and exchange. Moreover, it can be used to consider questions comparing different situations, e.g. do the natural sciences interpret and exercise science participation in a different way from the social sciences? Does science participation in the Anglophonic world look different from the Spanish-speaking world, as Greco (2004) suggests? The cube is a practical analysis tool to test hypotheses and to comprehend different practices.

The goal of the participatory science cube is not to represent projects in detail and reflect on the often nuanced and important differences between them, for example with respect to project goals, decision-making and power distribution within the project, or social context and understanding among the participants. For this, the tailored frameworks for description and analysis remain the method of choice. In addition to these frameworks we find it important to debate and analyse aspects besides the established categories (e.g. influence and empowerment), for example pleasure and delight experienced by participants, as Sarah Davies (2014) has proposed.

While the three axes span a full space for possible project locations, not all areas are equally likely. First, we expect some correlation between a strong epistemic focus and a strong normative focus, since when citizens have a strong say about the direction of research, this usually implies a strong normative component. As described above, the framework distinguishes between the normative influence limited to the project boundaries (which is considered for the categorization of the epistemic focus) and the normative openness beyond the immediate participants. However, drawing this line can be difficult and remains subject to individual judgement. Second, the reach correlates with the degree of publicness regarding the normative and epistemic focus: a participatory project with public influence has to have a reach beyond scientists and policymakers. Nevertheless, the usefulness of the framework to describe and distinguish participatory projects is not impacted by these predicted correlations.

When applying the cube to analyse existing citizen science and participatory approaches, the cube shares a limitation with the existing frameworks: the projects can rarely be categorized and located exactly, because their openness (on any of the three axes) varies between project components and also over time. Different actors may also

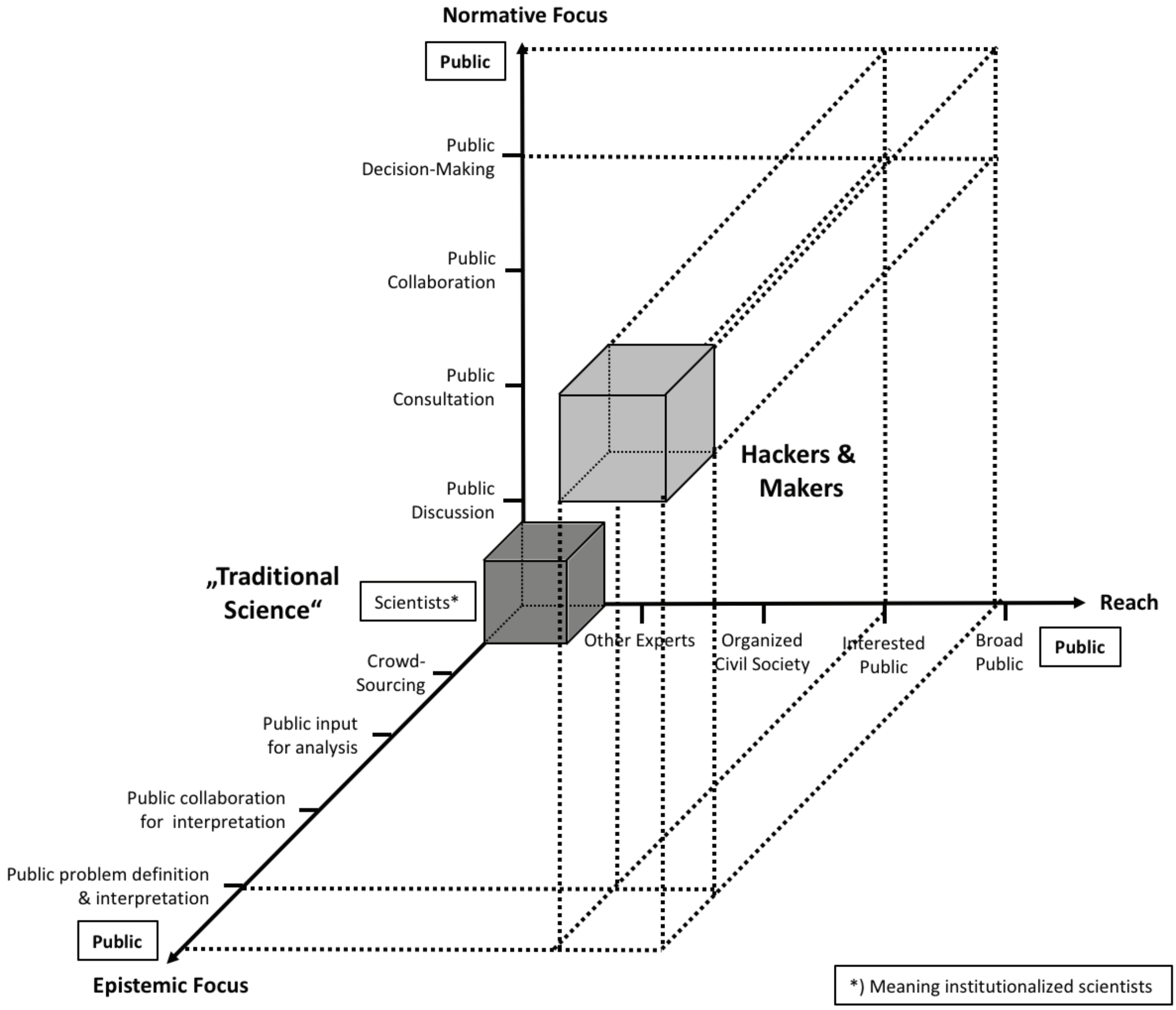

Figure 3: The participatory science cube with two prototypical manifestations of scientific projects on the opposite edges of the cube: traditional, closed, institutionalized science and open hacker or maker projects.

have different positions on the direction of the project. To address this, the projects within the cube are not represented as spots, but rather as areas. We chose cubes to illustrate our example, but stretched clouds and blurry boundaries are also possible.

To illustrate the rationale of the participatory science cube, we have inserted two prototypical manifestations of scientific projects, located in opposite corners of the cube (see figure 3). These manifestations are: 1) traditional, institutionalized science and 2) open hacker or maker projects. Traditional science means a project solely conducted by researchers from traditional scientific institutions without any public input and participation. This type of project is positioned in the back corner of the participatory science cube and reaches no degree of openness on any of the three axes. At the opposite corner of the cube are projects from the hacker/maker/fablab/DIY-science community (Wohlsen, 2011; Hatch, 2013; Walter-Herrmann and Büching, 2014). The DIY-science community promotes the conduct of scientific experiments outside established institutions with the purpose of democratizing science and also achieving educational outreach. Although the maker and fablab movements have a stronger focus on invention, innovation and technological developments, there is a large overlap with scientific research, especially since technology and new measurement approaches play an ever increasing role in today's research. Furthermore, specific projects like "science hack days" (Ornes, 2016) deepen the interaction between technologically motivated communities and scientific endeavours. These projects are placed at the maxima (most public classification) on the axes for the normative and epistemic focus within the participatory science cube. This position is justified by decisions being made solely by community members and the research activities being coupled with a strong set of normative beliefs in empowerment through science and technology and the concept of open science (Bartling and Friesike, 2014) similar to the ideas of participatory action research (von Unger, 2014). Scientific institutions are only included when they act as partners, for example when they provide access to laboratory equipment or machinery. Regarding their reach, these projects do not generally reach a broad public, as only the interested (and often also to some degree previously trained) participate intensively.

Populating the cube with case studies

We have stated that the participatory science cube bridges a gap in existing research regarding public inclusion in science. To illustrate that the cube makes it possible to map very different participatory science initiatives, we briefly present four different approaches to 'public science' and depict them on the cube. The selected projects represent quite different cases and have been selected in order to present the usefulness of the cube as an analytical and descriptive tool. The chosen examples are not intended to be exhaustive, but intend to inspire further applications of the cube. To cover a broad range of case studies, we followed a "most different systems design" approach (see Seawright and Gerring, 2008).

Crowdsourcing to identify African animals: Chimp&See

The first project, "Chimp&See", is a typical citizen science project that invites the general public to assist researchers in identifying species and describing their behaviour and general appearance. On a web-based platform, videos from camera-traps can be analysed and annotated by volunteers. The more 'lay researchers' take part, the more data are gathered and verified through multiple encoding. Participants do not need detailed biological knowledge: they receive a short introduction to their task, view images of wild animals online, identify the depicted species (supported by an identification key), as well as individual animals if possible, and annotate the animals' behaviour (Arandjelovic et al., 2016).

- **Normative Focus:** While participants may benefit personally by acquiring deeper knowledge of wild species and their behaviour and by taking part in a collaborative generation of knowledge, the normative dimension plays a minor role, only marginally contributing to a general discussion of species conservation and diversity beyond the immediate participants. The project is therefore located at the least public end of the axis, only reaching 'public discussion' at maximum.

- **Epistemic Focus:** The performance of repetitive tasks with a focus on pattern recognition is typical of a crowdsourcing project. Besides the encoding of the images, community-engagement activities and user support/motivation via social-media activities, public participants are not included further into the research process. The discussion between participants in the online forums, however, is sometimes taken up by the initiators of the project and may, in some cases lead to modification of the coding schemes. As this happens only occasionally, the epistemic focus for most participants is crowdsourcing (see also Data Shift, 2016), leading to the overall placement along the axis.
- **Reach:** The platform is open to anybody and therefore potentially addresses the general public. However, the voluntary work on animal identification and even the discovery of the platform requires prior interest in the topic. Typical participants are therefore characterized as belonging to the interested public.

Discussing emerging issues in science and technology: Citizen Dialogue on Future Technologies

The second example project is a dialogic format initiated by a government entity. The "Citizen Dialogue on Future Technologies/Topics", initiated by the German Federal Ministry of Education and Research (BMBF), was a national consultation process between 2011 and 2013.[3] The consultation covered one topic each year, with a total of three topics: energy technologies, high-tech medicine and demographic change. The consultation consisted of several aspects: for each topic six to eight citizen conferences with around 100 randomly-selected participants in cities across Germany, accompanying smaller citizen workshops, an open online-platform for comments and discussion, and a final citizen summit for each topic with participants from the earlier events. A roundtable with representatives from science, civil society and industry accompanied each process (Decker and Fleischer, 2012).

- **Normative Focus:** The aim of the consultation was to incorporate the perspectives of citizens regarding future technologies into advice for policy-makers. The policy advice was addressed through a final 'citizen report' developed by the participants of the citizen summit, based on the input from the whole dialogue process. This report had no binding implications for policy makers, but was distributed to politicians, administrators, and science, industry and civil society organisations involved in the process. The overall classification therefore places the project between 'public discussion' and 'public consultation'.
- **Epistemic Focus:** The citizen dialogue focused on governance issues ranging from research priority setting to potential limits on research. The participants had no systematic involvement in research processes (aside from a potential influence on individual participating researchers). Thus this project has no epistemic contribution in the framework and is located at the inward end of the axis.
- **Reach:** Although the number of participants in the discussion events was limited, the random polling (achieved through random phone calls with invitations to the events) and the geographically distributed events across the country ensured that not only the interested (typically highly-educated, older, male participants) contributed to the debate. To account for the response bias during the random selection, underrepresented groups were given priority for registration. Additionally, the online platform was open for anybody to participate. Therefore, a very broad public was reached with the project.

Scientific societies with profound 'lay' knowledge: the ORION entomologists

The third example is a scientific participatory format that has existed even longer than the term 'citizen science'. This long-established form of lay science takes place in scientific societies whose members share a common passion for a specific branch of science and work on it for years, acquiring skills and knowledge often superior to professional scientists. The entomological society "Orion", situated in Berlin, was established more than a hundred years ago. It is an example of 'lay experts' who intensively cultivate a special interest (e.g. for beetles), so that they gain a profound expert knowledge and publish their results in entomological publications, for example in the national inventory of beetles (Stiesy, 1990).

- **Normative Focus:** While the society also holds public presentations and the members are engaged in environmental conservation, the overall activities, beyond the members themselves, have no normative component with respect to science policy. In contrast to the hacker and maker community, traditional scientific civil society organisations like ORION mostly work within the established fields and procedures of institutionalized science. Therefore, they are not considered as a normative opening within the framework.
- **Epistemic Focus:** The members of the society define their own epistemic focus, conduct long-term research projects on certain species or go on excursions to collect data in specific areas. They also perform the analysis independently (and have, for example, negotiated permission to use the collections and part of the technical infrastructure of the Museum of Natural History in Berlin for reference) and publish their own results. The project therefore reaches the most outward public epistemic focus in the participative science cube framework.
- **Reach:** The activities of ORION are primarily limited to the members of the society. Even though presentations and excursions are open to the public, the reach beyond the members is limited. The society's reach is therefore categorized as organized civil society within the framework.

Scientific activism in air pollution monitoring: the Diamond bucket monitoring

The fourth and final example illustrates the importance of scientific data and evidence for lay citizens who wish to immediately influence political decisions. The inhabitants of the Diamond subdivision in Norco, Louisiana decided in the late 1990s to take scientifically-based actions on the air pollution they experienced living close to a Shell chemical plant. Fearing for their physical health, they started monitoring air pollution using simple sampling devices they referred to as "buckets". While the sample-taking was performed by the citizens, the actual analysis was performed with professional laboratories. The main issue of the conflict was not the measured values themselves, but the question of the definition of environmental standards (mean long-time exposure vs. local short-term exposure) and the official measurement frequency and distribution of measurement points (Macey, 2003; Ottinger, 2010).

- **Normative Focus:** While the overall goal of changing environmental standards and methods for monitoring was not achieved, the activists created public awareness and forced the Shell Company to initiate a multi-year supervised study of the local air quality and "may have contributed to regulators' decision to take enforcement [action] against Shell Chemical" (Ottinger, 2010: 246). Therefore, a true public decision-making was not achieved, but a public collaboration on the evidence-based enforcement of environmental standards was achieved.
- **Epistemic Focus:** Driven by a practical problem and serious health concerns, the inhabitants of communities neighbouring the chemical plant decided to start self-organized air monitoring. The community themselves addressed the problem definition, measurement strategies, sample taking and interpretation of the results (including the discussion of official standard definitions). The chemical analysis of the sample was performed by professional laboratories, but this would also have been the case had official experts measured the air quality. Therefore, the most participatory categorization with regard to the epistemic focus is still justified.
- **Reach:** The activities of the Diamond inhabitants were in principle open to the general public. However, only the community immediately affected by the problems constituted the core group of participants. Therefore, and because of the limited geographic reach, the project has not been placed in the most open category with regard to its reach.

The example projects within the participatory science cube

When the four example projects described above are visualized in the participatory science cube (see figure 4), the strengths and limitations of the descriptive framework become obvious.

On the one hand, the cube proves its value in categorizing and visualizing deliberative participatory approaches together with epistemic participation. It provides a good and easily accessible overview of different varieties of participation and can serve to inform further debates and developments. Also, when multiple projects are visualized in one framework, it is possible to identify participatory blind spots, where no projects exist so far. Also it may serve as a descriptive tool to grasp the evolving and popular field as citizen science. On the other hand, the examples show the limitations of the model: for the exact positioning of the projects within the cube, reasonable judgment is necessary. This may lead to different categorizations by different observers. Therefore, the visualization alone does not present a complete characterisation of the projects, since additional information and justification for the categorization is always necessary.

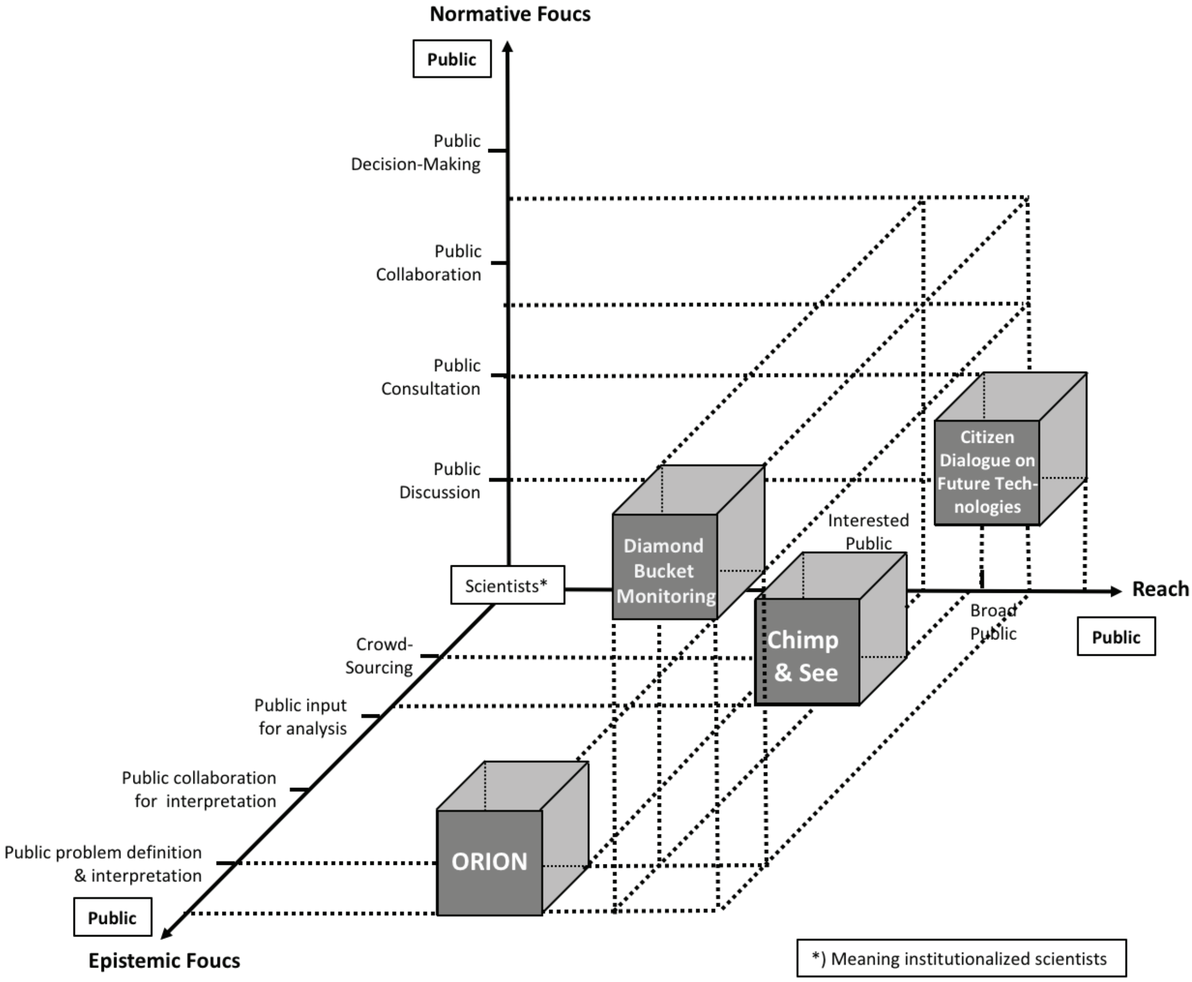

Figure 4: The participatory science cube with four example projects: "chimp&see" as a typical scientific crowdsourcing project, the citizen dialogue on future technologies as a public consultation on science policy, the activities of the ORION entomological society as scientific work conducted by researchers in a civil society organization and the Diamond bucket monitoring as an example of effective science activism.

Conclusion

In this article, we have argued for a holistic discussion of participation in science, bringing the two established academic silos of participatory, deliberative science governance and citizen science together. We have reviewed the existing models and typologies for participatory governance and citizen science and found that each of them looks almost exclusively at a single dimension while leaving out other dimensions. Therefore, we have looked for multi-dimensional frameworks for participation and found Archon Fung`s (2006) three-dimensional 'democracy cube' for participatory governance. After reviewing the 'democracy cube', we proposed an expanded 'participatory science cube' as an adaptation of the original model. The participatory science cube includes two axes building on the two core dimensions of deliberative participation and citizen science – the balance of the normative and epistemic focus between the public and scientists. The third axis shows the dimension of reach with regard to participating actors. We have shown how prototypical scientific approaches as well as concrete case studies fit into the cube and discussed the possibilities and limitations of its use.

For the participatory science cube, the academic saying: "Essentially, all models are wrong, but some are useful" (Box and Draper, 1987: 424) holds true. As presented here, the participatory science cube can serve as a model incorporating different forms of participation, from dialogue about science governance to actual participation in research processes. This model can be used to assess, compare and discuss different participatory approaches. However, it cannot cover individual experiences and reflect the various normative judgements on how participatory science ought to be done. Being aware of the limitations of the model, we hope to have presented a useful and accessible tool for a comprehensive discussion of the various ways of participating in science.

The democracy cube was developed as a descriptive typology, but discussions around citizen science and participation in science are often led by normative arguments, calling for a maximum degree of openness, inclusion and empowerment of non-traditional participants. And indeed, there is a large opposition to new approaches to scientific inquiry and participatory decision-making within traditional scientific institutions. Therefore, we strongly support the push towards a more open and inclusive governance and conduct of research. We hope that the 'participatory science cube' can be a helpful tool for the many discussions which need to be had to achieve this. But we also want to highlight that for us, *every* form of participations has its justification. As Barbara Prainsack (2014: 155) has stated: "we should not assume […] that all those who participate in projects where participants have only limited influence in project design are being exploited. For many, being part of something useful, being acknowledged publicly in publications, or learning about the scientific area in question is enough of an incentive to participate, and a satisfactory reward". For our understanding of the proposed 'participatory science cube' this means that there is no normative mandate to push all participatory approaches to the outermost corner of maximum openness, as long as the purpose, design, guidelines and limits for participatory projects are transparent, fair and clearly communicated to participants and the public.

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Notes

1) Further evaluation tools based on the quality of participation, exchange, and outcomes are presented by Tippett et. al 2007 and Lynam et al. 2007.

2) For this article and the proposed framework, 'scientists' refers to 'institutionalized scientists, professionally operating in the hierarchy of typical science organizations'. This would be 'normal science' or 'mode-1' science: idealized, disciplinary "pure" science independent of outside influence. The opening of science in general (towards a post-normal, mode-2, transdisciplinary, … science (compare Funtowicz and Ravetz 1995, Nowotny et al. 2003 and Hirsch Hadorn et al. 2008) and the subsequent new definition of the understanding of science itself would be reflected by a shift within the framework.

3) Disclosure: One of the authors, Philipp Schrögel, was involved in the planning and implementation of the dialogue process.

Jamie Cross, Simone Abram, Mike Anusas and Lea Schick (eds) (2017) Our Lives with Electric Things. Theorizing the Contemporary, *Fieldsights,* December 19, 2017. Society for Cultural Anthropology. https://culanth.org/fieldsights/series/our-lives-with-electric-things

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"Our Lives with Electric Things" was published online in December 2017 as part of *Fieldsights*' wonderfully experimental series called Theorizing the Contemporary. Growing out of earlier workshops on "Electrifying Anthropology" sponsored by the Wenner-Gren Foundation and convened at the University of Durham and ITU Copenhagen, the published collection is large (relative to other *Fieldsights* sections), with 51 entries organized into 17 groups of three. The entries follow a more or less uniform template and the collection as a whole reads like a catalog (a term used by the editors) or a social media feed: each entry represents a specific 'electric thing' with a short descriptive title (e.g., Gould's "Electric Candles", Badami's "Flatpack Sunlight", Angelini's "Overcharged" to name a few of my favorites); a single color photograph or illustration; and about 300 words written as first person anecdote by an anthropologist or STS/media theorist (which I discuss further below). This is a smart editorial decision. The simple uniformity and brevity of entries allow the heterogeneity and groundedness of the individual lenses and voices to shine. The familiar becomes strange, and the strange familiar — one of the most generative contributions of anthropology as a discipline.

Kudos to editors Jamie Cross, Simone Abram, Mike Anusas, and Lea Schick, for a refreshing assemblage of images, writing styles, and subjects. The entries are insightful and accessible — a good model for the use of digital media over print. The photographs are visually compelling; given room to breathe on a webpage and appearing in full color, the images work as intimate portraits of concrete things, as well as portals into everyday practices unfolding in multiple worlds. A variety of genres are represented: from tight close-ups like Ted Gordon's electric music box and wonderful domestic still lifes like Pamila Gupta's air conditioner, to landscape photos like Erin Parish's aerial view of La Chorrera waterfalls in Puerto Rico, action photos like Matthäus Rest removing curd from a vat at an alpine dairy in Switzerland, and great stolen shots like Barbara Carbon's framing of two mechanics in a dark Congolese hydroelectric plant. Photo captions and credits are precious, acting as small registers of a particular moment in a particular place lived by particular someones. (I do wonder why dates were left out — an oversight that rarely happens in documentary projects. Although the information likely exists in each photo's metadata, noting the date of capture is crucial in field-based work). The writing styles and genres range from diaristic prose to thick description, ethnographic and historical to poetic and speculative, personal to political and theoretical. Readers get to follow their curiosities and scroll through entries in no particular sequence. A few contributors use the format exceptionally well, experimenting with alternatives to long-form academic journal writing and more open approaches to analysis. In

"Accra Beauty Blue", Pauline Destree offers a poetic rendition of multiple affective registers of blue light in Ghana, technologies of desire that she calls "beauty blue". Trisha Phippard examines an ambivalent "human relationship to electrons" by writing about the technological promise as well as precarity that accompanies the arrival of a new x-ray machine in a hospital in a Congolese town of "1.2 million with no main-line electricity." On a different continent, Trang X. Ta is situated in the Sham Shui Po district of Hong Kong, where new and old devices and appliances are sold alongside heaps of remote controls "separated from their main components" and offered in a secondhand street market for discarded and obsolete electric things. Meanwhile, the highest concentration of wind turbines in the United Kingdom churn away in the Orkney islands to deliver power and electric futures to households that live in the highest levels of "fuel poverty" in Scotland; Rebecca Ford writes about Orkney electricity that is "both abundant and unaffordable," a local and global entanglement of markets, energy, and power.

By curating various things together, the editors aim to convey the seeming ubiquity of electricity, to make visible invisible currents that run through and organize contemporary life. Since the nineteenth century, with Thomas Edison's incandescent light bulb and electric utility company in Newark and then later George Westinghouse's alternating current system in Pittsburgh, electricity has been central to the making of colonial and modern forms of life, knowledge, wealth, and power around the world. But access to electricity has been violently uneven and historically contingent. In their introduction, the editors pose a rhetorical question: "Can we still imagine the possibility of lives without electric things?" This immediately begs a question that is being raised increasingly, in the humanities and social sciences, yet not enough: Who is this imagined 'we'? As noted earlier, the collection is curated into 17 sections, all of which begin with the possessive "Our". Thus, the sections begin with "Our Body Electric", "Our Electric Air", "Our Electric Backup", and so forth, until the final "Our Electro-Homes". Whose lives are referenced by the title, "Our Lives with Electric Things"? "Our Lives" implies universality but the entries argue against precisely that. The collection is neither an exhaustive catalog (cars and other vehicles, computers, and even cameras, for example, are strikingly absent) nor representative of a single common body or standpoint. There is no 'we'; there is no 'our'.

The collection offers what Donna Haraway (1988: 582-583) calls 'situated knowledge,' by which she means a feminist objectivity that "turns out to be about particular and specific embodiment and definitely not about the false vision of transcendence of all limits and responsibility… It allows us to become answerable for what we learn how to see". This, to me, is the project's key contribution and it is left unexamined. The contributors write from their particular locations, offering partial perspectives *from* — not *of* — worlds otherwise. As a member of the Karrabing Film Collective in northern territories of Australia, Elizabeth Povinelli (2016) collaborates on short videos (captured with handheld cameras and smartphones) that she describes as "improvisational struggles" within settler late liberalism or modes of "governance of difference and markets" that emerged in the 1960s. Rather than representations of indigeneity and colonial occupation, the Karrabing videos are enactments of what contemporary life is and can be from the perspectives of the dispossessed or again, what Haraway calls 'subjugated standpoints.' The diversity and scope of the collection powerfully suggest this kind of feminist politics at its heart, or its various hearts. Unfortunately, the editors miss the opportunity to take its pulse or at least point to its possibilities.

Instead, the aim of the collection is to "extend anthropology's contribution to the new energy humanities" and the editors hope to "electrify anthropology, and inspire a generation of anthropologists to think electric". "Our Lives", in this sense, means anthropologists' lives. Should the project be read as a collection *by* anthropologists and *for* anthropologists exclusively? I don't think this is what the editors intend. The energy humanities is an emerging field led by Cymene Howe and Dominic Boyer and Imre Szeman (2014) who argue for interdisciplinary approaches to the "energy dilemmas" of the Anthropocene, a highly debated umbrella term that tries to broadly describe a novel geological epoch dominated by humans and particularly industrialized capitalism.

I see how paying attention to electric things as artefacts and as material-semiotic practices enables consideration of various mechanisms of the Anthropocene in ways that other kinds of things might not. In a section titled "Our Electric Meters," Moyukh Chatterjee writes of illegal electricity meters in their building in Delhi as collective forms of agency that connect to and get cut off from the state, literally. Electricity is political. Playing off Foucault's (1976) concept of sovereign power, Chatterjee writes: "Faulty meters, red tape, and arbitrary meter readings transformed state officials into little sovereigns with the ability to give power or deny light". In the same section, Antina Von Schnitzler plays off Latourian sociality by describing electric meters in Kenya as instruments of measurement that are performative, "a material-semiotic practice that produces realities, rather than merely representing them". Then there are flows and transformations of energy that rethink the personal and the political across history and scale. Jonathan Devore's "Watermill" in a section called "Our Electric Exchanges" is about a homemade hydroelectric watermill in Bahia, Brazil that is used to charge an old battery which lights a bulb for a landless rural family. Devore connects the lightbulb to the Brazilian state's rural electrification initiatives and unevenly distributed electrical grids. In these entries, electricity not only illuminates but mediates power and agency, creating and disrupting affordances, enacting the art and science of governing and *not* being governed. Indeed, "electric things are good to think with" as the editors write. Following electricity from multiple perspectives articulates how the Anthropocene is not a foregone conclusion but a complex of situated everyday practices through which matter and energy are constantly being transformed. This is another contribution worthy of editorial comment.

My last point inquires after the kinds of methods that may be drawn from ethnographic attention to the polysemic and prosthetic nature of electric things, the multiple meanings, capacities, and relations that are produced at multiple scales when transformations occur in both expected and unexpected ways (when Phippard's x-ray machine breaks down, for example). Electric things *are* good to think with because they hold kinetic and potential energy; they can be plugged and unplugged; they can become absolutely essential and then quickly obsolete unless they might be rigged, updated or hacked in between. Electric things are methods, experiences, and artefacts, simultaneously: with electric things we make and make do, even as who 'we' might be gets made and unmade through things that range from a screwdriver circuit tester in Lubumbashi (Rahier) to Facebook data centers in Odense (Winthereik), from *baraat laltens* or celebratory lamps carried by musicians in Uttarakhand (Partridge) to provisional energy infrastructures in the form of floating powerships anchored in Ghana's harbor (Günel).

In 2007, Amiria Henare, Martin Holbraad, and Sari Wastell edited a provocative volume titled *Thinking Through Things*. They argue for an "artefact-oriented anthropology" that refuses too-quick applications of pre-existing theory to ethnographic material and instead works toward articulating methods through which the material itself draws out theory. They describe their project as methodological, calling on anthropologists to "attend to 'things' as they emerge in diverse ethnographic settings, and to begin such investigations with what, for the ethnographer, may appear as a logical reversal: rather than providing data to which theory is applied, revealing the strengths and flaws of an existing theoretical model, the things encountered in fieldwork are allowed to dictate the terms of their own analysis — including new premises altogether for theory" (Henare et al., 2007: 4). Electric things can electrify anthropology — and more broadly, studies of the messy and unruly entanglements of the Anthropocene — in precisely this way.

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Sergio Sismondo (2018) *Ghost-Managed Medicine: Big Pharma's invisible hands.* Manchester: Mattering Press. 231 pages. eISBN: 97809955277782

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Drug companies do everything they can to sell their products. This, in itself, is not surprising. After all, that's what businesses do. But do we really know what drug companies do and the extent of their influence? After reading Sergio Sismondo's book *Ghost-Managed Medicine*, we realised we knew only a fraction of what is really happening. Sismondo exposes pharmaceutical companies' extensive involvement in knowledge production. His arguments are compelling. Yes, one can read about how corporate-funded research tends towards publishing only favourable results, and about the fancy hotels and bonusses doctors receive when promoting the company's products. But this is not what the book is about. What *Ghost-Managed Medicine* is really about is the invisible ('ghost') orchestration ('managed') of medical knowledge production by the pharmaceutical industry.

This focus and scope of the book positions it in a strong STS tradition of opening the black box of the construction of scientific facts. Sismondo convincingly demonstrates how industry is involved in *all* aspects of medical knowledge production, circulation and consumption. Considering the secretive character of corporate activities, it is impressive how the author has found his way into their political economies of knowledge production. Since many of company activities are outsourced and have to be promoted to their target groups (physicians) there is a highly-developed infrastructure of communication. It is in these promotion and educational meetings that Sismondo undertook ethnographic research. On the basis of this data he describes in detail what he calls 'assemblage marketing': how "a pharmaceutical company creates a market by producing, shaping and transporting research and medical journal articles, as well as opinion leaders and patient advocates. It pushes these in the expectation of influencing regulators, physicians, patients and other useful actors" (p. 23). Reading the book, it becomes clear how the pharmaceutical industry not only finance medical trials but are also involved in their design, in running the trials, undertaking the statistical analysis, writing the articles, selecting the journals and at the very end of the process inviting a well-known academic researcher to author the publication. This last move makes it almost impossible to distinguish the result from other academic research. Sismondo stresses that this in itself does not imply scientific flaws. The problem lies in the fact that scientific knowledge is entirely imbued with corporate interests that have been comprehensively removed from view. Research, in other words, acts as a Trojan horse for marketing.

However, the activities of drug companies do not stop here. Going beyond ghost-writing, Sismondo reveals how drug companies exert their influence in continuing medical education, through the co-opting and manipulation of 'key opinion leaders'. In some cases, drug companies even market symptoms and syndromes, initially in an 'unbranded' campaign, and as such shape public views of what to consider as healthy and unhealthy. Once need for a remedy is established, the product waiting in the wings can then quickly take centre stage. In this way drug companies penetrate doctors' consulting rooms, hospital wards, patient associations, and enter the thought-processes of patients.

The strength of this book lies in the detailed analysis of pharmaceutical companies' strategies of control over medical knowledge production – these are pervasive and unremitting, even to the point of aligning journal editors' interests with those of pharmaceutical companies. No stone is left unturned. The result is to completely undermine any semblance of objectivity in research and individual agency of doctors – both highly valued concepts in medicine. Where the book is weaker is in relation to the tactics of sales representatives. This chapter confirms suspicions but does not take our understanding beyond what one might expect. Nevertheless, we would like to suggest that 'doctors-to-be' should become aware of these processes. Being involved in the training of medical doctors and medical researchers we, Jessica Mesman and Dawn Goodwin, think that *Ghost-Managed Medicine* is an important text for students for the following reasons. Sismondo's book provides the means with which to teach students in the field of medicine core STS insights about the influences of the wider social and cultural context in which scientific knowledge is produced. The book illustrates the different relations between science and society, laying out in particular the role of industry and its complex and far-reaching influence. In this way, doctors-to-be and those who pursue a career in medical research become aware of corporate challenges to independence and the mechanisms through which industry exerts its influence in medical knowledge production on macro-, meso- and micro-levels. The book does all this with limited reference to sociological concepts and terminology. The connections to sociological bodies of work are clearly evident to those who would recognise them, and are explained explicitly in the opening chapter, but then the book speaks directly and plainly – an enormous benefit when teaching students who are required to develop social science understandings but without social science backgrounds.

To road test our view, we asked two students - Pierre Springuel and Sean Jensen – for their opinions:

> Reading 'Ghost-managed medicine', for the first time in our careers, shed light on the pharmaceutical industry's veiled involvement in nearly all aspects of medical sciences. It describes the various interventions, hidden agendas and parties of the industrial machine involved in the creation, distribution and uptake of medical information. With responsibility as paramount as health, these supposed directors of our well-being are heavily scrutinised and approached with scepticism, we were keen to explore the extent to which this scrutiny and scepticism could be justified.
>
> Reading the book, we were quickly faced with the reality that pharmaceutical companies control a significant portion of the information that professionals and public alike can access. Methods range from data manipulation, ghost-writing and public censorship to the recruitment of prestigious clinicians, researchers and communication companies to mindlessly parrot pharmaceutical agendas. To our dismay, it became blatantly evident we were ignorant of these ongoing practices, especially as biomedical students destined to one day become actors on Big Pharma's stage.
>
> These crafty and manipulative conducts need to be recognised by the general public, and especially by future medical practitioners and researchers who often unknowingly act as marionettes of the pharmaceutical industry. We feel that the way to most effectively integrate this reality for the benefit of both the public and the industries is

for attention to be brought on these issues. We believe this to be especially important for the next generation of scientists in the medical industry - us.

We advocate open discussion of the complicated issues brought up by Sismondo in small group seminars. There are no simple answers to the ethical concerns that arise with the pharmaceutical industry's influence, and so discussion is key. Discussing these matters in a critical manner, dissecting the problems and potential solutions, not only exposes but educates students on the current workings. The point of discussion is not to "solve the issue", but to critically evaluate arguments so that we can be aware and hopefully make well-informed decisions. We believe this to be the best way to equip students with the tools necessary to act in a more ethical manner when challenged by exogenous pressures.

So students and tutors agree – this book holds important lessons for future medical practitioners and researchers, those who value the objectivity of medical research and their independence as decision-makers.

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