In press, for *Science and Technology Sciences*, 2018

"Citizen Science"? Rethinking Science and Public Participation

Bruno J. Strasser*, Jérôme Baudry, Dana Mahr, Gabriela Sanchez & Elise Tancoigne

University of Geneva, Uni Carl Vogt, 1211 Geneva 4, Switzerland

*corresponding author: bruno.strasser@unige.ch

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 contextualises "citizen science" within the broader history of public participation in science and analyses critically the current promises — democratisation, 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

Acknowledgements

We would like to thank Dominique Pestre, Jennifer Shirk, François Grey, and Muki Haklay for helpful comments on an earlier version of this manuscript, as well the Swiss National Science Foundation for generous funding through a Consolidator Grant BSCGIO_158887 (BJ Strasser).

Introduction

There is probably no such thing as "citizen science", yet there might be at least fifty shades of 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 processing power of their personal computer to perform scientific calculations (SETI@home), to amateur naturalists collecting observational data outdoors about birds (eBird) and city residents mapping air pollution (City Sense), to people classifying online images of galaxies from home (Galaxyzoo), to patients sharing quantified observations, symptoms, and experiences about their health (PatientsLikeMe), and to 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). Yet, it is still unclear whether the very 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

[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.

professional scientists working in dedicated research institutions and the lay public. 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 co-production 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 & 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 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.

1. What is "Citizen science"?

1.1. 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 differs 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), 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 focussed 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 is on "local" and "contextual" knowledge produce by citizens, which differs qualitatively from knowledge produced in scientific institutions. His concern echoes the debates then taking places in science and technology studies and feminist epistemology about "indigenous knowledge" (Watson-Verran and Turnbull 1995) and "situated knowledge" (Haraway 1988). Irwin would like 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 labelled 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 notion of "citizen science" pointed in a very 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), 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, in terms of science education "Citizen science was the magic bullet the NSF was looking for" (Bonney 2016).

Bonney (and the NSF) viewed "citizen science" as public participation in scientific research *and* as 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", "layperson", "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).

1.2. 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 focussed 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 which places "co-created" projects as a superior mode of "citizen science", since it goes further in involving the public's participation, echoing the public policy analyst Sherry R. Arnstein's influential "ladder of participation" developed in the context of participatory urban planning (Arnstein 1969). 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 the 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). These kind 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 focussed 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 (Wiggins and 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 most attention in the media.

We propose a rather different typology of the practices that have been labelled “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; analysing; 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 analyse (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 “analysing” 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 form 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 May 2015, participants had reported more than 9.5 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 smartphones 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 analyse radio signals that might indicate the existence of extra-terrestrial 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.

Analysing. 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 Galaxyzoo (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 the 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 are also designated as “crowdsourcing” (Howe 2005; Brabam 2013) and cover a wide range of tasks, such as classifying images like in Galaxyzoo, 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 though “participatory” slogans such as “Let’s make healthcare 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, 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 nonprofit organization dedicated to promoting citizen science and access to biotechnology in the greater New York Area" or 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" or "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 analysing the variety of public participation projects in terms of their individual epistemic components, the individual genealogies of these "ways of knowing", as John Pickstone has put it, can be disentangled (Pickstone 2000).

2. 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, Zuckerberg, and Bonter 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).

2.1. 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"), where 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 very 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 very different 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). But the importance of domestic spaces for science was not restricted to the house of experiment in 17th century England and "domestic science" has 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 after all, Darwin 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 which 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 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). Yet behind these attempts at unification unifying attempts, a number of very different 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. In terms of 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 an increasingly wide gap between professional (experimental) scientists and the public. As *Popular Science Monthly* put it in 1902, thinking of the experimental sciences: “The era of the amateur scientist is passing; science must now be advanced by the professional expert” (Anonymous 1902). 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 as a result of the professionalization of science, but also as a shift in the centre of gravity of the sciences from one kind of epistemic practice, where amateurs were very present, to another where they were mostly excluded, even though in some case 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. But 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 a very different historical perspective than the usual reference to nineteenth century amateur naturalists.

2.2. Radical Science Movements in the 1960s and 1970s

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, Topçu, and Bonneuil 2013; Jarrige 2016), focussing 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 fuelled 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 as 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 which emerged earlier (and continue to the present day), based on the involvement of the public in *deliberations* about science and technology which dominated the ideals of public participation in the 1980s and 1990s.

Indeed, in the 1980s, a number of “institutional experimentations” (Chilvers & 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 citizen 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 have labelled the “Mode 2” of knowledge production (Nowotny, Scott, and Gibbons 2002). But this time, “the people” had an actual say in what it considered the public interest, however, it turned out, mostly at the very end of the research and development process. An 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, focussed 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 centres 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, Mikkelsen, and Harr 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 very particular 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.

3. 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.

3.1. 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 democratisation 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 fulfil 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, 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 seriously the democratization argument 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, for example. As in all other online communities, such as Wikipedia, there are great levels of inequality in the amount of contributions by participants (Haklay 2017).

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 biogeographic long-term 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.

2.2. 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. But a more contextual understanding of these educational promises should highlight why increasing "scientific literacy" has become a task for "citizen science" to fulfil. Part of the answer, we suggest 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).

Beginning in the immediate post World War II era, 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 fuelled 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 a sustained attention to its framing as a solution to (international) educational challenges.

3.3. 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 enrolment of 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 to 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 Galaxyzoo, where volunteers analyse 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).

But understanding the contribution of volunteers to participatory research through the number of papers published or the economic value of volunteer labour 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 by either one, 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 area of scientific research covered by participatory research does not always overlap with that currently investigated by academic science. This does not undermine the value of participatory research, but 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 reach 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, of 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). But 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,* the 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 raised to the 6th of the game in part because of his personal abilities: 'I can look at something and see that it's not right'." (Hand 2010). Another player described her special "feel" for proteins (Boyle, Editor, and News 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, the citizens' 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)

Analysing 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 is the 1970s, by AIDS patients in the 1980s, or by residents of toxic neighbourhoods 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 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 is able to transform *how* knowledge is being produced, at a deep epistemological level, then it could hold an 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. But we also need to move from “citizen science” to participatory research or even inquiry (Heron & 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 focussed 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, analysing, 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, 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 & 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 brought 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, Tremblay, and Moraes 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 contextualisation for studies of "citizen science" (Kindon, Pain, and Kesby 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 which 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 citizen's 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). 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 explore empirically the consequences of various arrangements of experts and laypeople 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.

References

23AndMe (2016) Accelerating Research. Available at: https://www.23andme.com/en-int/research/ (accesses 23.12.2016).

Alberti SJMM (2001) Amateurs and Professionals in One County: Biology and Natural History in Late Victorian Yorkshire. *Journal of the History of Biology* 34 (1): 115–147.

Allen DM (2009) Amateurs and Professionals. In: Bowler PJ & Pickstone JV (eds) *The Cambridge History of Science. The Modern Biological and Earth Sciences.* Cambridge, UK: Cambridge University Press 15–33.

Anonymous (1902) Democracy and the Recognition of Science. *The Popular Science Monthly*, March, 477–78.

Arnstein SR (1969) A Ladder Of Citizen Participation. *Journal of the American Institute of Planners* 35 (4): 216–24.

Barrow MV (1998) *A Passion for Birds: American Ornithology after Audubon*. Princeton, NJ: Princeton University Press.

Beckwith JR (2002) *Making Genes, Making Waves : A Social Activist in Science*. Cambridge, Mass.: Harvard University Press.

Benderly BL (2016) Displaced American STEM Workers Spur Senate Hearing. *Science*, March 3. Available at: doi:10.1126/science.caredit.a1600036 (accessed 23.12.2016).

Bensaude-Vincent B (2003) *La science contre l'opinion : Histoire d'un divorce*. Paris: Les Empêcheurs de Penser en Rond.

Bonney R (1996) Citizen science: A Lab Tradition. *Living Bird* 15: 7–15.

Bonney R (2016) Citizen science – Innovation & Inspiration for Science. *First International ECSA Conference.* Berlin: ECSA, May 20, 2016.

Bonney R, Ballard HL, Jordan R, McCallie E, Phillips T, Shirk J & Wilderman CC (2009) *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report*. Washington, D.: Center for Advancement of Informal Science Education (CAISE).

Bonney R, Phillips TB, Ballard HL, and Enck JW (2016) Can Citizen Science Enhance Public Understanding of Science? *Public Understanding of Science (Bristol, England)* 25 (1): 2–16.

Boston Women's Health Book Collective (ed) (1971 [2011]) *Our Bodies, Ourselves*. New York: Simon & Schuster.

Boudia S & Jas N (eds) (2016) *Powerless Science?: Science and Politics in a Toxic World*. New York, Oxford: Berghahn Books.

Boyle A (2011) Gamers Solve Molecular Puzzle That Baffled Scientists. *NBC News*. September 18. Available at: http://www.nbcnews.com/science/science-news/gamers-solve-molecular-puzzle-baffled-scientists-f6C10402813 (accesses 23.12.2016).

Brabham DC (2013) *Crowdsourcing*. Cambridge, Mass: The MIT Press.

Brown P (1997) Popular Epidemiology Revisited. *Current Sociology* 45 (3): 137–56.

Brown P (2007) *Toxic Exposures - Contested Illnesses and the Environmental Health Movement*. New York: Columbia University Press.

Brown P & Mikkelsen EJ (1997) *No Safe Place: Toxic Waste, Leukemia, and Community Action*. Oakland, CA: University of California Press.

Bucchi M & Neresini F (2007) Science and Public Participation. In: Hackett EJ, Amsterdamska O, Lynch ME & Wajcman J (eds) *The Handbook of Science and Technology Studies*. Cambridge, Mass: The MIT Press, 449–72.

Carson R (1962) *Silent Spring*. Greenwich, Conn: Fawcett.

Chandler M, Bebber DP, Castro S, Lowman MD, Muoria P, Oguge N & Rubenstein DI (2012) International Citizen science: Making the Local Global. *Frontiers in Ecology and the Environment* 10 (6): 328–31.

Chilvers J & Kearnes M (eds) (2015) *Remaking Participation: Science, Environment and Emergent Publics*. London ; New York: Routledge.

Christiano T (2015) “Democracy.” In: Zalta EN (ed) *The Stanford Encyclopedia of Philosophy*, Spring 2015. Available at: http://plato.stanford.edu/archives/spr2015/entries/democracy/ (accessed 23.12.2016).

Clickworkers (2000) Welcome to the clickworkers study. Available at Internet Archive Wayback Machine: http://clickworkers.arc.nasa.gov/top (accesses 23.12.2016).

Coleman WR (1971) *Biology in the Nineteenth Century : Problems of Form, Function and Transformation*. Cambridge: Cambridge University Press.

Common Sense (2009) What if every mobile device had an air quality sensor? *Common Sense — Mobile sensing for community action*. Available at Internet Archive Wayback Machine: http://communitysensing.org/people.php (accessed 23.12.2016).

Cooper S (2015) Science of the People, by the People and for the People. *Scientific American Blog Network*. September 30. Available at: https://blogs.scientificamerican.com/guest-blog/science-of-the-people-by-the-people-and-for-the-people/ (accessed 23.12.2016).

Cooper C & Lewenstein BV (2016) Two Meanings of Citizen Science. In: Cavalier D & Kennedy EB (eds) *The Rightful Place of Science: Citizen Science*, Tempe AZ, CSPO, 51-61.

Coren MJ (2011) Foldit Gamers Solve Riddle of HIV Enzyme within 3 Weeks. *Scientific American*, September 20. Available at: https://www.scientificamerican.com/article/foldit-gamers-solve-riddle/ (accessed 23.12.2016).

Counter Culture Labs (2013). Available at Internet Archive Wayback Machine: https://counterculturelabs.org (accesses 23.12.2016).

Cronje R, Rohlinger S, Crall A and Newman G. (2011), Does Participation in Citizen Science Improve Scientific Literacy? A Study to Compare Assessment Methods. *Applied Environmental Education & Communication* 10, no. 3 (July 2011): 135–145.

CSA (2009) Citizen Science Alliance. Available at Internet Archive Wayback Machine: http://www.citizensciencealliance.org/ (accesses 23.12.2016).

Cunningham A & Williams P (1992) *The Laboratory Revolution in Medicine*. Cambridge ; New York: Cambridge University Press.

Curtis V (2015) *Online Citizen science Projects: An Exploration of Motivation, Contribution and Participation*. PhD Thesis, The Open University, UK.

Daston L & Galison P (2007) *Objectivity*. New York: Zone Books.

Dear PR (2001) *Revolutionizing the Sciences : European Knowledge and Its Ambitions, 1500-1700*. Princeton, NJ: Princeton University Press.

Debailly R (2015) *La critique de la science depuis 1968: Critique des sciences et études des sciences en France après Mai 68*. Paris: Hermann.

DeBoer GE (1991) *A History of Ideas in Science Education : Implications for Practice*. New York: Teachers College Press.

DeBoer GE (2000) Scientific Literacy: Another Look at Its Historical and Contemporary Meanings and Its Relationship to Science Education Reform. *Journal of Research in Science Teaching* 37 (6): 582–601.

DeBoer GE (2011) The Globalization of Science Education. *Journal of Research in Science Teaching* 48 (6): 567–91.

Delfanti A (2013) *Biohackers: The Politics of Open Science*. London: Pluto Press.

Delgado A (2013) DIYbio: Making Things and Making Futures. *Futures* 48 (April): 65–73.

Dickinson JL, Zuckerberg B & Bonter DN (2010) Citizen science as an Ecological Research Tool: Challenges and Benefits. *Annual Review of Ecology, Evolution, and Systematics* 41 (1): 149–172.

eBird (2002) About. Available at Internet Archive Wayback Machine:

http://www.ebird.org/about/index.jsp (accessed 23.12.2106)

Egan M (2007) *Barry Commoner and the Science of Survival : The Remaking of American Environmentalism*. Cambridge, Mass: MIT.

Endersby J (2008) *Imperial Nature: Joseph Hooker and the Practices of Victorian Science*. Chicago: University of Chicago Press.

Epstein S (1996) *Impure Science : AIDS, Activism, and the Politics of Knowledge*. Berkeley: University of California Press.

European Commission (2015) Citizen science, July 7. Available at: https://ec.europa.eu/digital-single-market/en/citizen-science (accessed 23.12.2106).

European Commission (2016) Science with and for Society - Horizon 2020. Available at: https://ec.europa.eu/programmes/horizon2020/en/h2020-section/science-and-society (accessed 23.12.2106).

Fausto-Sterling A (1992) *Myths of Gender: Biological Theories about Women and Men*. New York, NY: BasicBooks.

Felt U & Wynne B (eds) (2007) *Taking European Knowledge Society Seriously*. Brussels: European Communities.

Field H & Powell P (2001) Public Understanding of Science versus Public Understanding of Research. *Public Understanding of Science* 10 (4): 421–26.

Fleming JR & Johnson A (eds) (2014) *Toxic Airs: Body, Place, Planet in Historical Perspective*. Pittsburgh, Pa: University of Pittsburgh Press.

Floodcrowd (2016) About. Available at: http://floodcrowd.co.uk/ (accesses 23.12.2016).

Freire P (2000 [1968]) *Pedagogy of the Oppressed*. New York: Continuum.

Gonforth C (2016) Citizen science. Available at: http://naturalsciences.org/research-collections/citizen-science (accesses 23.12.2016).

Grey F (2012) 2nd London Citizen Cyberscience Summit 16-18 February. Available at: http://citizencyberscience.net/blogs/index.php/category/volunteer-computing/ (accesses 23.12.2016).

Gutberlet J, Tremblay C & Moraes C (2014) The Community-Based Research Tradition in Latin America. In: Munck R, McIlrath L, Hall B & Tandon R (eds) *Higher Education and Community-Based Research*. New York: Palgrave Macmillan, 167–80

Haklay M (2013a) Citizen science and Volunteered Geographic Information: Overview and Typology of Participation. In: Sui D, Elwood S & Goodchild M (eds) *Crowdsourcing Geographic Knowledge*. Dordrecht: Springer Netherlands, 105–22

Haklay, M (2013b) Neogeography and the Delusion of Democratisation. *Environment and Planning* A 45 (1): 55–69.

Haklay M (2017, in press) Participatory Citizen Science. Berlin: ECSA

Hand E (2010) Citizen science: People Power. *Nature News* 466 (7307): 685–87.

Haraway D (1988) Situated Knowledges: The Science Question in Feminism and the Privilege of Partial Perspective. *Feminist Studies* 14 (3): 575-599

Haring K (2008) *Ham Radio's Technical Culture*. Cambridge, Mass: The MIT Press.

Harkness DE (2007) *The Jewel House: Elizabethan London and the Scientific Revolution*. New Haven: Yale University Press.

Herodotou C, Sharples M & Scanlon E eds. (2017) *Citizen Inquiry: Synthesising Science and Inquiry Learning*. Oxon: Routledge.

Heron, J & Reason P (1997) A Participatory Inquiry Paradigm. *Qualitative Inquiry* 3 (3): 274–94.

Himanen P (1999) *Hacker Ethic and the Spirit of the Information Age*. New York: Floris Books.

Hobsbawm EJ & Ranger T (eds) (1983). *The Invention of Tradition*. Cambridge: Cambridge University Press.

Holohan A (2013) *Community, Competition and Citizen Science: Voluntary Distributed Computing in a Globalized World.* London: Ashgate Publishing.

Horowitz S, Koepnick B, Martin R, Tymieniecki A, Winburn AA, Cooper S, Flatten J, *et al*. (2016) Determining Crystal Structures through Crowdsourcing and Coursework. *Nature Communications* 7 (September): 12549.

Howe J (2006) The Rise of Crowdsourcing. *Wired*, January 6. Available at: https://www.wired.com/2006/06/crowds/ (accesses 23.12.2016).

Irwin A 1995 *Citizen science: A Study of People, Expertise, and Sustainable Development*. London ; New York: Routledge.

Irwin A 2006 The Politics of Talk Coming to Terms with the 'New' Scientific Governance. *Social Studies of Science* 36 (2): 299–320.

Jarrige F (2016) *Techno-Critiques: Du refus des machines à la contestation des technosciences*. Paris: La Découverte.

Jasanoff S (2003) Technologies of Humility: Citizen Participation in Governing Science."*Minerva* 41 (3): 223–44.

Jasanoff S (ed) (2004) *States of Knowledge: The Co-Production of Science and Social Order*. London ; New York: Routledge.

Jasanoff S (2013) *Science and Public Reason*. London; New York: Routledge.

Kaiser D McCray WP (eds) (2016) *Groovy Science: Knowledge, Innovation, and American Counterculture*. Chicago: University of Chicago Press.

Kera D 2015 Open Source Hardware (OSHW) for Open Scicence in the Global South: Geek Diplomacy? In: Albagli S, Maciel ML & Abdo AH (eds) *Open Science, Open Issues.* Rio de Janeiro: Brasilia IBICT, 133–56.

Kickstarter (2010) BioCurious: A Hackerspace for Biotech. The Community Lab for Citizen Science. Available at Internet Archive Wayback Machine: https://www.kickstarter.com/projects/openscience/biocurious-a-hackerspace-for-biotech-the-community (accesses 23.12.2016).

Kim JS, Greene MJ, Zlateski A, Lee K, Richardson M, Turaga SC, Purcaro M, *et al*. (2014) Space-Time Wiring Specificity Supports Direction Selectivity in the Retina. *Nature* 509 (7500): 331–336.

Kindon S, Pain R & Kesby M (eds) (2010) *Participatory Action Research Approaches and Methods: Connecting People, Participation and Place*. London; New York: Routledge.

Kline W (2010) *Bodies of Knowledge: Sexuality, Reproduction, and Women's Health in the Second Wave*. Chicago: The University of Chicago Press.

Kohler RE (2002) Place and Practice in Field Biology. *History of Science* 40 (128 pt 2): 189–210.

Kosmin BA & Navarro-Rivera J (2008). The Salience of Secular Values and Scientific Literacy for American Democracy. In: Keysar A & Kosmin BS (eds) *Secularism & Science in the 21st Century*, 173–90. Hartford, CT: ISSSC.

Kullenberg C (2015) Citizen science as Resistance: Crossing the Boundary Between Reference and Representation. *Journal of Resistance Studies* 1 (1): 50–76.

Kuznick PJ (1987) *Beyond the Laboratory: Scientists as Political Activists in 1930's America*. Chicago: University of Chicago Press.

Lawrence C & Shapin S (eds) (1998). *Science Incarnate: Historical Embodiments of Natural Knowledge*. Chicago: University of Chicago Press.

Lear LJ (1997) *Rachel Carson : Witness for Nature*. New York: Henry Holt.

Lengwiler M (2007) Participatory Approaches in Science and Technology: Historical Origins and Current Practices in Critical Perspective. *Science, Technology & Human Values* 33 (2): 186–200.

Leslie, SW (1993) *The Cold War and American Science : The Military-Industrial-Academic Complex at MIT and Stanford*. New York: Columbia University Press.

Lingscape (2016). Lingscape. Available at: http://engelmann.uni.lu/lingscape/> (accesses 23.12.2016).

Longino HE (1990). *Science as Social Knowledge: Values and Objectivity in Scientific Inquiry*. Princeton NJ: Princeton University Press.

Mahr D & Prüll L (2017, *in press*) Körperliche Selbstermächtigung Aus Dem 3D Drucker? Feministische Kulturen als 'Parallelwelten' und Der Kampf Um Gesellschaftliche Teilhabe Seit 1970. In: Buckermann P (ed) *Systematische Un/Ordnung - Zum Verhätnis von Digitaler Technologie Und Gesellschaftlicher Emanzipation*.

Mahr, D (2014) *Citizen science: Partizipative Wissenschaft Im Späten 19. Und Frühen 20. Jahrhundert*. Baden-Baden: Nomos.

Marshall, J (2012) Victory for Crowdsourced Biomolecule Design. *Nature*, January 22. Available at: http://www.nature.com/news/victory-for-crowdsourced-biomolecule-design-1.9872 (accesses 23.12.2016).

Masters K, Oh EY, Cox J, Simmons B, Lintott C, Graham G, Greenhill A, & Holmes K. (2016). Science Learning via Participation in Online Citizen Science. *arXiv:1601.05973 [Astro-Ph, Physics:physics]*, January 22, 2016. http://arxiv.org/abs/1601.05973.

McCray, WP (2008) *Keep Watching the Skies!: The Story of Operation Moonwatch and the Dawn of the Space Age*. Princeton: Princeton University Press.

McGourty C (2016) Scientists Seek Galaxy Hunt Help. *BBC News.* Available at: http://newsvote.bbc.co.uk/mpapps/pagetools/print/news.bbc.co.uk/2/hi/science/nature/6289474.stm (accesses 23.12.2016).

McQuillan, D (2014) The Countercultural Potential of Citizen science. *M/C Journal* 17 (6). Available at: http://journal.media-culture.org.au/index.php/mcjournal/article/view/919 (accesses 23.12.2016).

Méndez BJH (2008) SpaceScience@Home: Authentic Research Projects That Use Citizen Scientists. In: EPO and a Changing World: Creating Linkages and Expanding Partnerships. Available at: http://adsabs.harvard.edu/abs/2008ASPC.389.219M (accesses 23.12.2016).

Mody CCM (2016) The Professional Scientist. In: Lightman B (ed) *A Companion to the History of Science*. Malden, MA: Wiley-Blackwell, 164–77.

Moore K (2008) *Disrupting Science : Social Movements, American Scientists, and the Politics of the Military, 1945-1975*. Princeton: Princeton University Press.

Morgen S (2002) *Into Our Own Hands: The Women's Health Movement in the United States, 1969-1990*. New Brunswick, N.J: Rutgers University Press.

Nambisan P (2011) Information seeking and social support in online health communities: impact on patients' perceived empathy. *Journal of the American Medical Informatics Association* 18 (3): 298-304.

National Science Foundation (2002). *Informal Science Education (ISE) - Program Solicitation - NSF 03-511*, Arlington, Virginia: NSF. Available at: https://www.nsf.gov/pubs/2003/nsf03511/nsf03511.pdf (accesses 23.12.2016).

National Science Foundation (2002). *Informal Science Education (ISE) - Program Solicitation - NSF 04-579*, Arlington, Virginia: NSF. Available at: (https://www.nsf.gov/pubs/2004/nsf04579/nsf04579.pdf (accesses 23.12.2016).

Nelson J (2015) *More Than Medicine: A History of the Feminist Women's Health Movement*. New York: NYU Press.

Nieto-Galan A (2016) *Science in the Public Sphere: A History of Lay Knowledge and Expertise*. Abingdon, Oxon: Routledge.

Nowotny J, Scott P & Gibbons M (2002) *Re-Thinking Science : Knowledge and the Public in an Age of Uncertainty*. Cambridge: Polity.

OED (2015) *Oxford English Dictionary*. Available at: http://www.oed.com/ (accesses 23.12.2016).

Opitz DL, Bergwik S & Van Tiggelen B (eds) (2016) *Domesticity in the Making of Modern Science*. London: Palgrave Macmillan.

Ottinger G (2016) Social Movement-Based Citizen Science. In: Cavalier D & Kennedy EB (eds) *The Rightful Place of Science: Citizen Science*, Tempe AZ, CSPO, 89-103

PatientsLikeMe (2016) Live better, together! Available at: https://www.patientslikeme.com/ (accesses 23.12.2016).

Perkel JM (2008) Protein Computer Games: Me Fold Pretty One Day. *Scientific American*. October 14. Available at: https://www.scientificamerican.com/article/protein-computer-games-foldit/ (accesses 23.12.2016).

Pessis C, Topçu S & Bonneuil C (2013) *Une Autre Histoire des "Trente Glorieuses" : Modernisation, contestations et pollutions dans la France d'après-guerre*. Paris: La Découverte.

Pestre D (2011) Des sciences, des techniques et de l'ordre démocratique et participatif. *Participations*, no. 1 (October): 210–38.

Petersen JC (ed) (1984) *Citizen Participation in Science Policy*. Amherst: University of Massachusetts Press.

Pham, NQ, Tran HN, Thi KVL, Nong AB & Rutten MM (2015) Ecosystem service monitoring using remote sensing, citizen science and other ground observations and current practices in Vietnam. Available at: http://resolver.tudelft.nl/uuid:031dab85-cd80-462d-9b7c-4a5da79a8c64 (accesses 23.12.2016).

Pickstone, JV (2000) *Ways of Knowing: A New History of Science, Technology and Medicine*. Manchester: Manchester University Press.

Poo Power! (2012) Poo Power! under the Scope. Available at Internet Archive Wayback Machine: http://www.poopower.com.au/our-story/poo-power-under-the-scope.html (accesses 23.12.2016).

Prost A (1999) Frontières et espaces du privé. In: Ariès P & Duby G (eds) *Histoire de La Vie Privée*, Paris: Seuil, 13–132.

Public Lab (2016) Balloon Mapping Kit. Available at: http://publiclab.myshopify.com/products/balloon-mapping-kit (accesses 23.12.2016).

Putnam RD (2001) *Bowling Alone: The Collapse and Revival of American Community*. New York: Simon & Schuster.

Quet M (2013) *Politiques du savoir. Sciences, technologies et participation dans les années 1968*. Paris: Archives contemporaines.

Rabeharisoa V & Callon M (2002) The Involvement of Patients' Associations in Research." *International Social Science Journal* 54 (171): 57–63.

Raddick MJ, Bracey G, Gay PL, Lintott CJ, Murray P, Schawinski K, Szalay AS & Vandenberg J (2010) Galaxy Zoo: Exploring the Motivations of Citizen science Volunteers."*Astronomy Education Review* 9 (1). Available at: https://arxiv.org/abs/0909.2925 (accesses 23.12.2016).

Ravetz J & Westfall RS (1981) Marxism and the History of Science. *Isis* 72 (3): 393–405.

Reed J, Raddick MJ, Lardner A & Carney K (2013) An Exploratory Factor Analysis of Motivations for Participating in Zooniverse, a Collection of Virtual Citizen science Projects. In: 46th Hawaii International Conference on System Sciences: 610–19. IEEE.

Riesch H & Potter C (2014) Citizen Science as Seen by Scientists: Methodological, Epistemological and Ethical Dimensions. *Public Understanding of Science* 23 (1): 107–20.

Rudolph JL (2000) *Scientists in the Classroom : The Cold War Reconstruction of American Science Education*. New York: Palgave.

Sarmenta LFG (2001) *Volunteer Computing*, PhD Thesis, MIT.

Sauermann H & Franzoni C (2015) Crowd Science User Contribution Patterns and Their Implications. *Proceedings of the National Academy of Sciences* 112 (3): 679–84.

Saurugger S (2010) The Social Construction of the Participatory Turn: The Emergence of a Norm in the European Union. *European Journal of Political Research* 49 (4): 471–95.

Secord A (1994) Science in the Pub: Artisan Botanists in Early Nineteenth-Century Lancashire. *History of Science* 32: 269–315.

Serrano F (2013) Engaging Citizens in Science for Research Excellence." *Science Node*. October 16. Available at: https://sciencenode.org/feature/engaging-citizens-science-research-excellence.php (accesses 23.12.2016).

Shapin S (1988) The House of Experiment in 17th-Century England. *Isis* 79 (298): 373–404.

Shapin S (1996) *The Scientific Revolution*. Chicago: University of Chicago Press.

Shapin S & Schaffer S (1985) *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*. Princeton: Princeton University Press.

Shirk JL, Ballard HL, Wilderman CC, Phillips T, Wiggins A, Jordan R, McCallie E, et al. (2012) Public Participation in Scientific Research: A Framework for Deliberate Design. *Ecology and Society* 17 (2): 29.

Sieber RF & Haklay M (2015) The Epistemology(s) of Volunteered Geographic Information: A Critique. *Geo: Geography and Environment* 2 (2): 122–36.

Silvertown J (2009) A New Dawn for Citizen science. *Trends in Ecology & Evolution* 24 (9): 467–71.

Smith, PH (2006) *The Body of the Artisan: Art and Experience in the Scientific Revolution*. Chicago: University of Chicago Press.

Smithsonian (2016) Visitor Statistics. Available at: http://newsdesk.si.edu/about/stats (accessed 23.12.2016).

Socientize (2013) Green Paper on Citizen science. Available at: http://www.sciencedirect.com/science/article/pii/S0301421500001427 (accesses 23.12.2016).

Sonnert G & Holton GH (2002) *Ivory Bridges : Connecting Science and Society*. Cambridge, Mass.: MIT Press.

Stardust (2006) Stardust@home. Available at Internet Archive Wayback Machine: http://stardustathome.ssl.berkeley.edu/ (accesses 23.12.2016).

Stilgoe J, Lock SJ & Wilsdon J (2014) Why Should We Promote Public Engagement with Science? *Public Understanding of Science* 23 (1): 4–15.

Strasser BJ (2012) Collecting Nature: Practices, Styles, and Narratives. *Osiris* 27 (1): 303–40.

Strasser BJ & Mahr D (2017) Experiential Knowledge, Public Participation, and the Challenge to the Authority of Science in the 1970s. Harvard Law Bill of Health, May 2, 2017. Available at: http://blogs.harvard.edu/billofhealth/2017/05/02/experiential-knowledge-public-participation-and-the-challenge-to-the-authority-of-science-in-the-1970s/

Sullivan III WT, Werthimer D, Bowyer S, Cobb J, Gedye D & Anderson D (1997) A new major SETI project based on Project Serendip data and 100,000 personal computers. In: Cosmovici CB, Bowyer S & Werthimer D (eds) *Astronomical and Biochemical Origins and the Search for Life in the Universe*, *Proc. of the Fifth Intl. Conf. on Bioastronomy.* Bologna: : Editrice Compositori.

Surowiecki J (2005) *The Wisdom of Crowds*. New York: Anchor.

Takahashi D (2013) More than 1.2 Billion People Are Playing Games. *VentureBeat*. November 25. Available at: http://venturebeat.com/2013/11/25/more-than-1-2-billion-people-are-playing-games/ (accesses 23.12.2016).

Topçu S (2013) *La France nucléaire : L'art de gouverner une technologie contestée*. Paris: Seuil.

uBiome (2016) Discover Your Microbiome. Available at: https://ubiome.com/explorer (accesses 23.12.2016).

Universcience (2015) Rapport d'activité 2014. Available at: http://www.universcience.fr/francais/rapport-activites-2014/ (accessed 23.12.2016).

Vetter J (2011) Introduction: Lay Participation in the History of Scientific Observation. *Science in Context* 24 (2): 127–141.

Watson D & Floridi L (2016) Crowdsourced Science: Sociotechnical Epistemology in the E-Research Paradigm. *Synthese*, October, 1–24. Available at: doi:10.1007/s11229-016-1238-2 (accessed 23.12.2016).

Watson-Verran H & Turnbull D (1995) Science and Other Indigenous Knowledge Systems. In: Jasanoff S *et al*. (eds) *Handbook of Science and Technology Studies*, Thousand Oaks, CA: SAGE Publications, chapter 6

White P (2016) The Man of Science. In Lightman B (ed) *A Companion to the History of Science*. Chichester, UK : Wiley-Blackwell, 153–163.

Wiggins A & Crowston K (2011) From Conservation to Crowdsourcing: A Typology of Citizen science. In: *Proceedings of the 2011 44th Hawaii International Conference on System Sciences*. Washington, DC: IEEE Computer Society, 1-10.

Wilford JN (1970) Knitting□Needle Thrust Interrupts One Dissident. *The New York Times*, December 30. Available at: http://www.nytimes.com/1970/12/30/archives/knittingneedle-thrust-interrupts-one-dissident.html (accesses 23.12.2016).

Wittner LS (2009) *Confronting the Bomb : A Short History of the World Nuclear Disarmament Movement*. Stanford, Calif.: Stanford University Press.

World Bank (1996) *The World Bank Participation Sourcebook*. Washington, D.C: World Bank.

Wright A (2010) Managing Scientific Inquiry in a Laboratory the Size of the Web, *The New York Times*, December 28, 2010, p. 3

Wylie SA, Jalbert K, Dosemagen S & Ratto M (2014) Institutions for Civic Technoscience: How Critical Making Is Transforming Environmental Research. *The Information Society* 30 (2): 116–26.

Wylie A & Sismondo S (2015) Standpoint Theory, in Science. Available at: http://philpapers.org/rec/SISSTI (accesses 23.12.2016).

Wynne B (2006) Public Engagement as a Means of Restoring Public Trust in Science – Hitting the Notes, but Missing the Music? *Public Health Genomics* 9 (3): 211–220.

Yeo RR (1993) *Defining Science : William Whewell, Natural Knowledge, and Public Debate in Early Victorian Britain*. Cambridge: Cambridge University Press.

Zooniverse (2009) Zooniverse. Available at Internet Archive Wayback Machine: https://www.zooniverse.org/ (accesses 23.12.2016).

Zooniverse (2016) About the Zooniverse. Available at: http://zooniverse.org/about (accesses 23.12.2016).