Citizen science

Expertise, democracy, and public participation

Report to the Swiss Science Council

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Executive summary

"Citizen science" refers to a broad range of activities where people produce scientific knowledge outside of traditional scientific institutions. From mapping natural phenomena, to analyzing scientific data, sharing health information, and making new technologies, citizen science occurs across all the disciplines of science and involves a number of different methods of inquiry, both orthodox and alternative. It includes projects directed by scientists and by grassroots organizations as well as projects where power over the design, implementation, and the use of outputs is shared among participants and organizers.

Citizen science is not a completely novel phenomenon since it was the main mode of practicing science for centuries. But the professionalization of science and the rise of experimentalism since the mid-nineteenth century has increasingly separated professional scientists from the public, and this accelerated in the second part of the twentieth century. Citizen science, and other participatory research activities, reconnect professional scientists and the public in new ways. Unlike previous attempts at bridging the gap between science and the public through science communication or through deliberative forums, in citizen science the public directly contributes to the production of knowledge, though in many cases their role is restricted to data collection or simple analysis.

Citizen science is witnessing a rapid growth and is increasingly being recognized by national governments and science funding agencies as a promising solution to three sets of problems affecting the relationships between science and society. First, citizen science can contribute to science by providing a large workforce to solve research problems that require extensive observations (mapping biodiversity) or the analysis of big data sets (classifying galaxies). It can also contribute new DIY research tools, foster Open Science, and bring more inclusive methods to scientific research. Second, it can contribute to improving citizens' scientific literacy, specifically with regard to the nature of science and scientific inquiry, which is crucial for the ability of citizens to position themselves in democratic debates about scientific and technical issues. Third, it can contribute to making science more democratic, both in the sense of including more diverse people in the practice of science and in making science better aligned with the public interest. It can also increase public trust in science and help governments fulfil their international monitoring obligations, for example for biodiversity or air quality.

The great opportunities of citizen science for science, education, and democracy, but also the risks of cooptation by scientific institutions and of populist undermining of professional expertise deserve serious critical attention from scholars and policy makers. To encourage the more positive outcomes, the report includes policy options for science policy, funding agencies, and research and higher education institutions. In particular, we recommend indorsing citizen science and its awareness among policy makers and implementers, scientists, science funding bodies, and appropriate publics. We also indorse the suggestion to create a one-point entry body in organizations that engage with citizen science to facilitate the implementation of best practice across disciplines.

Specifically, for funding agencies, we suggest that citizen science be considered a major tool for public engagement, but also that agencies support wider uses of citizen science in regular research applications and their evaluation. There is also a need to have a broad set of evaluation criteria specific for citizen science. A program of "mini-research grants" can be an effective way to engage citizens in research and integrate citizen science within the wider public research landscape.

In terms of higher education and research organizations, we emphasize the need to take into account the economic situation of citizens and grassroots organizations and the need to provide public access to scientific literature. We encourage school science education to engage with citizen science, as it provides opportunities for authentic learning about science. There are numerous possibilities to involve the public in many aspects of environmental monitoring, for example, which can be beneficial for science, education, and democracy. Finally, citizen science should be supported as a complement to, not a replacement of, institutional science.

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"It is important to remember that amateurs built the Ark
and it was the professionals that built the Titanic"

Dr. Ben Carson (@RealBenCarson), Twitter, October 29, 2015
(pic.twitter.com/6Nqod4sicS)

"I think that the people of this country have had enough of experts
with organisations […] *with acronyms—saying that they know*
what is best and getting it consistently wrong"

Michael Gove MP (UK's Secretary of State for Justice), Interview
on Sky News, June 6, 2016

1. Introduction

The term citizen science is gaining a growing attention because it speaks to a number of current concerns about the proper place of science and expertise in society. Today's political populism, so evident in a 2015 tweet of former US presidential candidate Ben Carson and a 2016 interview of UK's former Secretary of State for Justice Michael Gove, does not express itself as a clash of social classes — the virtuous people against the corrupt elites — but as a clash of expertise — the virtuous amateur against the corrupt (professional) expert. The political discussion around the notion of "alternative facts" speaks to the central place given to factual knowledge produced by professional experts for the functioning of democratic societies. If expert knowledge loses its legitimacy, on what basis will public deliberation take place? And if the public distrusts scientific expertise, how will public policy justify itself? The rise of public controversies around scientific issues that have been considered as settled by professional scientists, such as the role of humans in climate change or the link between vaccination and autism, has revealed that the public's blind trust in science could not be taken for granted. Furthermore, it showed that educated citizens might be well-versed in basic scientific knowledge but were often ignorant of the process of scientific research itself, and filter scientific information according to their worldview, regardless of the level of education (in the United States, higher education level of Republicans is correlated with *lower* belief in climate change). These debates show that even if citizens trust scientific institutions, they also trust alternative and incommensurable sources of knowledge.

The issue of trust in science does not only affect the public, it is also a growing concern among scientists. Heated discussions on topics from the "replication crisis" to "scientific misconduct" and from "altmetrics" to "open science" indicate that the scientific community is engaged in a serious reflexive moment about how it produces robust scientific knowledge. Thus, understanding the various meanings of citizen science, the practices subsumed under that expression, and the debates surrounding this kind of science serve to illuminate, more broadly, the deep tensions that are currently affecting the place of science and expertise in society.

There is no such thing as citizen science, but this is a report about it.[1] Indeed, instead of taking citizen science as a thing that can be measured and described, distinct from the rest of scientific practice, we take it as a *label* that is increasingly being applied to a wide and heterogenous range of practices aimed at producing scientific knowledge with the active engagement of people operating outside the usual places of scientific work (universities, research institution, or corporation). Although the term is of recent coinage (mid-1990s, *Section* 2.2), and has only spread globally in the twenty-first century (*Section* 2.3) after being adopted by several national and supranational governmental organizations (*Section* 8), the values that guide current participatory research have a long history, and are actually as old as science itself (*Section* 3). But how these values and ideals have been translated into concrete practices has differed over time. Putting citizen science into this broader perspective will allow to better understand its full potential, but also its risks, for science as well as for society.

2. What does "citizen science" mean today?

One way to understand the polymorphous nature of "citizen science" is to look first at a range of practices that are currently being associated with the term in a number of scientific disciplines. Self-labelled, "citizen science" projects can be found in the physical sciences, life sciences, social sciences, formal sciences, applied sciences, and even in the humanities, although more rarely so (and from now on will be designated without quotation marks). They are about empiricism: the systematic collection of data and information, their analysis, and the use of scientific methods, techniques, and tools. Before looking at definitions, we start with an overview of the different activities that are generally recognized as part of citizen science,

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[1] For an introduction to citizen science by an advocate, see Cooper 2016a and for an introduction to critical issues Cavalier & Kennedy 2016 and an overview of new research questions, Strasser et al. 2018.

under the heading of their dominant epistemic practice: computing, sensing, analyzing, self-reporting, and making.

[box following 5 sections]

Computing

In 1998, a group of computer scientists and astronomers launched SETI@home at the University of Berkeley, the first Internet-based citizen science project. They invited people to share the idle processing power of their personal computers to analyze radio signals that might indicate the existence of extraterrestrial intelligence (SETI stands for Search for Extraterrestrial Intelligence). For SETI scientists, involving the public in a “distributed computing” network was a cheaper alternative than buying access to centralized mainframe computers. By 2001, SETI@home had attracted over three million participants. 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 (from the Swiss Tropical and Public Health Institute, the first project to simulate disease transmission), among many others.[2] Today, BOINC is also available on devices such as phones, tablets and even game consoles. Large scale “volunteer computing” projects have also been embraced by corporate sponsors, such as IBM, which supports the IBM World Community Grid. It hosts projects such as Computing for Clean Water, established by the Citizen Cyberscience Centre at the University of Geneva, which analyzes the potential of nanotube in water filtering, engaging researchers from China, Israel, Australia, the United Kingdom, and Switzerland.[3]

Sensing

In 2002, the Cornell Lab of Ornithology and the National Audubon Society launched eBird, a National Science Foundation (NSF)-supported online platform dedicated to recording the migration of birds. Once the system started to fulfill the needs of bird watchers (such as managing their observation list), the system became highly successful. By 2018, participants

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[2] Anderson 2004.

[3] Ma et al. 2015.

had reported half a billion bird observations on all continents of the globe.[4] eBird and other similar projects, such as iNaturalist, are a digital incarnation of a long tradition in natural history that draws on people's familiarity with their local environment and the capacity of large numbers of participants to expand the spatial reach of observational projects carried out by scientific organizations, such as the Swiss Ornithological Institute since 1924.[5] Sensing projects range from observations of biological and physical phenomena such as earthquakes in the US Geological Survey project "Did You Feel It?" to observations of the linguistic distribution of road signs in project Lingscape in Luxembourg. Digital technologies, such as smartphones, which follow people in their everyday lives, have facilitated the recording and sharing of observations, such as urban noise to create "soundscapes". The proliferation of affordable sensors has expanded even more the possible range of observations, including air quality.[6]

Analyzing

In 2006, a NASA spacecraft landed back on earth, quite dusty after spending almost seven years in space. Scientists from the UC Berkeley Space Sciences Laboratory 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.[7] Since then, a number of similar projects have emerged, such as Galaxy Zoo (2006) — determine the shape of galaxies — or Penguin Watch (2014) — count penguins in large colonies — many of which are present on the Zooniverse web platform, founded by 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", or "People Powered Research" as the organizers put it.[8] These projects are also designated as "crowdsourcing" and cover a wide range of tasks, such as classifying scientific images (Galaxy

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[4] https://ebird.org/news/a-new-face-for-ebird-redesigned-homepage (accessed, 2.3.2018).

[5] https://www.inaturalist.org/, http://www.vogelwarte.ch (accessed, 2.3.2018).

[6] https://earthquake.usgs.gov, https://lingscape.uni.lu/, http://www.opensourcesoundscapes.org/, www.communitysensing.org (accessed, 2.3.2018).

[7] "Stardust@home" 2006, available at Internet Archive Wayback Machine: http://stardustathome.ssl.berkeley.edu/ (accessed, 2.3.2018).

[8] "Zooniverse" 2009, available at Internet Archive Wayback Machine: www.zooniverse.org/ (accessed, 2.3.2018).

Zoo), locating dialects on a map (din dialäkt), or analyzing existing scientific data by playing games (Foldit, EteRNA), where people fold molecules in three-dimensions.[9]

Self-reporting

Riding on the success of medical information websites and social networks, several participatory 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 data (self-reported symptoms and illness-narratives) and quantitative data (patient records, genomic and other laboratory test results, and self-tracking health data). The information is then pooled for research purposes. The projects are advertised through participatory slogans such as “Let’s make healthcare better for everyone through sharing, support and research” or “Join the thousands of citizen scientists who have had their microbiome sequenced”.[10] Another type of self-reporting occurs in areas where participants share their perceptions of place in a systematic way. For example, in the Hush City project, participants record noise levels with their smartphone, but also their subjective perception of the city soundscape.[11] Similarly, with the Mappiness app, participants report how happy they feel in a specific location, geo-localized by their smartphone.[12]

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”, funded through a crowdfunding campaign on Kickstarter.[13] 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 make

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[9] Howe 2006, Brabham 2013, www.dindialaekt.ch, www.fold.it, www.eternagame.org/ (accessed, 2.3.2018).

[10] PatientsLikeMe 2016, available at Internet Archive Wayback Machine: www.patientslikeme.com (accessed, 2.3.2018); uBiome 2012, available at Internet Archive Wayback Machine: ubiome.com (accessed, 2.3.2018).

[11] Radicchi 2017.

[12] MacKerron and Mourato 2013.

[13] BioCurious, https://www.kickstarter.com/projects/openscience/biocurious-a-hackerspace-for-biotech-the-community (accessed, 2.3.2018).

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".[14] 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 or La Paillasse in Paris. Often inspired by computer hacker spaces and foregrounding the "hacker spirit", these spaces illustrate epistemic practices based on "making" things and producing knowledge in laboratories.[15]

2.1 The four key concepts of citizen science

The term citizen science entered the Oxford English Dictionary in 2014: "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".[16] A number of similar definitions have been proposed, for example, in 2013, the SOCIENTIZE Expert group for the European Commission's Digital Science Unit wrote: "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."[17] These definitions all describe citizen science as a type of science in which the *general public* contribute to the *production* of *scientific knowledge*, either alone, or more often in collaboration with professional scientists and scientific institutions. These definitions express four key ideas.

The first idea is that citizen science is a kind of scientific practice involving "(ordinary) citizens", "amateurs", "lay-people", "non-professionals", or "non-experts". Here, citizen science stands in contrast with "professional", "institutional", "academic", or "corporate" science which involves only professional scientists and excludes people who do not have a formal scientific education (usually a PhD). The assumption behind their exclusion is that the practice of science requires a kind and a level of expertise that non-professionals lack. Advocates of citizen science challenge this assumption by arguing that even with minimal skills

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[14] Counter Culture Labs 2013, available at Internet Archive Wayback Machine: www.counterculturelabs.org (accessed, 2.3.2018).

[15] Himanen 1999, Delfanti 2013.

[16] *Oxford English Dictionary*. Available at: http://www.oed.com/ (accessed, 2.3.2018).

[17] Socientize 2013, p. 6.

people can contribute to science meaningfully and that when more advanced skills are required they can be acquired by non-professionals.

The second idea is that citizen science is about non-professionals *producing* knowledge, i.e. being involved in the material and cognitive process of scientific research or inquiry. Non-scientists can contribute to producing knowledge by calculating (volunteer computing), sensing (recording environmental data), self-reporting (providing personal data), analyzing (analyzing existing scientific data), or making (performing experiments and producing DIY technologies). Citizen science stands in contrast with other forms of "public participation" in which the public is engaged in *deliberation* about the direction of scientific research, the risks of technologies, or ethical issues related to science (*Section* 3.4).

The third idea is that citizen science is about producing *scientific* knowledge, i.e. knowledge that can be recognized by a (professional) scientific community as following established scientific methods. Citizen science stands in contrast with other attempts to broaden participation in the production of knowledge or in decision making which recognize "lay", "local", "experiential", "indigenous" and other forms of non-professional knowledge as being *on a par* with scientific knowledge. Some citizen science projects do, however, challenge methodological assumptions of scientific research, but without questioning the superiority of science as a way of knowing about the natural world.

The fourth idea, which is rhetorically present in most citizen science projects but practically only in a few, is that citizen science should promote social and/or environmental justice (or "make the world a better place"). It should not be carried out primarily for the interest of science or scientists, but for the underprivileged and the marginalized. This goal captures part of social scientist Alan Irwin's original idea of democratizing science in the sense of making science better serve "the people" (*Section* 2.2). Notice that in this framing, the term "citizen scientist" can also be used to describe professional scientists who are dedicating their effort to addressing social or environmental issues in collaboration with marginalized groups.

2.2 The origins of the term citizen science

With its current meaning, the expression citizen science was coined around 1990 and its usage expanded dramatically after 2010 (*Section* 2.3). It diverges in a crucial way from the earlier meaning of the expression "citizen-scientist", "citizen scientist", or more rarely "citizen-science" that was used from the 1940s to the 1970s. In this period, "citizen-scientist" (usually with a hyphen) designated a professional scientist who, in addition to his/her occupation as a researcher, worked towards the achievement of common societal goals, or a professional scientist whose research aims and practices were explicitly influenced by societal goals. A "military scientist" and an "industrial scientist" worked for the military and for industry, but a "citizen scientist" devoted his/her career to achieving broader societal objectives, like reducing poverty or limiting environmental damage.[18] In 1943, an American philosopher argued, in the context of the Tennessee Valley Administration that "this citizen-scientist is a new cultural species".[19] By 1960, the term had become quite common and the United States Special Assistant to the President for Science and Technology stated in *Science* that "this new breed of citizen-scientist shall be continually aware that the scientific community must accept its appropriate share of the responsibility for the intelligent and successful resolution of the challenges facing the world."[20] This view of the role of scientists in society became most prominent in the late 1960s in radical science movements such as Science for the People in the United States, the British Society for Social Responsibility in Science in the UK, and Survivre et Vivre in France (*Section* 3.3). By contrast, the current "citizen scientist" is a *citizen*, which is a non-professional scientist contributing to research outside of his/her professional occupation, not a professional *scientist* guided by civic concerns.

The present meaning of citizen science is usually traced back to two publications. The first is the British social scientist Alan Irwin's 1995 book entitled *Citizen Science: A Study of People, Expertise and Sustainable Development*.[21] Irwin's goal was to make science and technology policy more "democratic", by listening to the voices of ordinary citizens and taking seriously their non-scientific knowledge. By doing so, Irwin argued, science could better serve the interests of citizens. Although Irwin's work is often cited in reference to current practices labeled as citizen science, it is more of a reflection on the participatory ideals — and their limitations — of the 1970s than on the practices currently subsumed under the label citizen science. Today, citizen science focuses on the *production* of (not deliberation about) scientific knowledge outside of scientific institutions and mostly following the norms and values of

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[18] For a contemporary usage of this term, Stilgoe 2009.

[19] Fries 1943, p. 433.

[20] Kistiakowsky 1960, p. 1023.

[21] Irwin 1995.

institutional science, thus not including alternative forms of knowledge as Irwin and others called for.[22]

The second, and far more relevant, origin of the current meaning of citizen science is a magazine article published independently in 1996 by the American ornithologist Rick Bonney from the Cornell Laboratory of Ornithology. Bonney 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".[23] Bonney had been supported by the NSF to study and promote the educational role of "Public Participation in Ornithology", following up the established tradition of amateur ornithology (*Section* 3.1). The NSF, which would go on to play a major role in promoting citizen science in the United States, understood citizen science first as an educational tool aimed at improving scientific literacy through "informal science education" for a broad public. A secondary benefit of the citizen science approach would be to contribute to the research goals of academic scientists. Although he became one of its greatest popularizers, Rick Bonney was not the first to use the term citizen science with its current meaning. Earlier examples include a 1989 article published by the National Audubon Society, an American environmental organization, which reported on how its "Citizens' Acid Rain Monitoring Network" depended "on 'citizen science' not just for data collection but also for educating the general public about issues that are usually limited to the scientific community."[24]

The term citizen science grew in popularity in the United States and in Europe following Bonney's definition, with a focus on contributing to education and to science at the same time. Although citizen science is also often discussed in reference to its contribution to "democratizing science" (*Section* 7), this aim is understood as broadening the section of the general population involved in the production of scientific knowledge. A second, more political understanding of "democratization", implied in Irwin's acceptation and more generally in the radical science movements of the 1960s and 1970s, is largely, but not entirely, absent from current discourse and practice around citizen science.

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[22] We disagree here with Cooper and Lewenstein 2016, who equate Irwin's citizen science model with "bottom-up" and Bonney with "top-down" forms of citizen science, overlooking that for Irwin the citizens' knowledge contribution is of a different nature than for Bonney.

[23] Bonney 1996.

[24] Bolze and Beyea 1989.

In Europe, in addition to citizen science, “Bürgerwissenschaft”, “sciences citoyennes”, and “ciencia ciudadana” have become increasingly common expressions. However, because of the different historical trajectories of the relationships between science and society in various national contexts, and even more so with the various political valences of the term “citizen”, “Bürger”, “citoyen”, or “ciudadano” these expressions are not strictly equivalent. In France, for example, “science citoyenne” retains a much more activist meaning, akin to “radical science” or “activist science” in the American or British contexts, and the more accurate French equivalent of citizen science is “recherche participative” (“participatory research”).

2.3 Diverse uses of the term citizen science

The usage of the term citizen science is expanding. This is not only due to the growing number of participatory initiatives being launched, but also to the fact that existing participatory initiatives are being relabeled as citizen science. As a result, a great diversity of practices can be found under that heading. Several typologies have been proposed to account for this diversity. One of the most widely used typologies sorts the different kinds of initiatives according to the locus of power in defining what research question is being addressed. Influenced by Sherry Arnstein’s classical “ladder of citizen participation” (1969), an inquiry group of the Center for Advancement of Informal Science Education (CAISE) in Washington DC defined five types of citizen science projects ranked from the smallest to the largest degree of control given to participants: 1) “Contractual projects”, in which professional researchers are asked by members of the public to address a specific scientific investigation and report on the results; 2) “Contributory projects”, which in most cases are set by professional scientists and the public primarily contribute data or resources; 3) “Collaborative projects”, which most frequently are designed by scientists, while members of the public contribute by refining research questions and the design, as well as collect and analyze data and disseminate the finding; 4) “Co-created projects”, in which the scientists and members of the public are working together on the design and operation of all or most aspects of the research process; and 5) “Collegial projects”, where non-credentialed individuals conduct research independently.[25] Muki Haklay expanded this typology (under different names) by including “extreme citizen science” as an additional level beyond “co-created” where citizens or grassroots organizations initiate the research projects before engaging, or not, in a collaboration

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[25] Arnstein 1969, Bonney et al. 2009, Shirk et al. 2012.

with scientists.[26] The typology we use here ("calculating", "sensing", "self-reporting", "analyzing", and "making") focuses on the kind of epistemic activity carried out by the participants and is more inclusive than previous typologies since it covers projects which are not necessarily explicitly labeled as citizen science and leaves open the question of the actual power given to participants.

As these typologies make clear, the term citizen science is now being used to designate activities covering a wide spectrum of modes of engagement between scientists and the public. Most of the activities labeled citizen science are "top-down", controlled by scientists who are inviting the public to assist them in a well-defined window of activity. However, beyond citizen science there is a range of participatory initiatives involving citizens in the production of scientific knowledge. At the "empowered citizen" end of the spectrum, one finds "community-based (action) research" (or "participatory action research"), which is inspired by the work of the American psychologist Kurt Lewin (1946) and the Brazilian popular educator Paulo Freire (1968). Working at the MIT, at a time of growing emphasis on "basic research", Lewin argued that if social sciences were to have any effect on the world, like the natural sciences did so evidently during the war, social scientists had to "consider action, research and training as a triangle that should be kept together for the sake of any of its corners."[27] By becoming involved in the research on intergroup relationships for example, minorities would become trained in understanding social situations *and* contribute effectively to improving their relationships with other groups. Paulo Freire, in his *Pedagogy of the Oppressed* ([1968] 2000), was less concerned with the relationship between researcher and research subject, than the relationship between educator and student. For him it was the teaching relationship which represented the best opportunity, not for the transmission of existing knowledge, but for the collaborative production of new knowledge aimed at changing the social situation of students.[28] These approaches have led to numerous research-education-action initiatives tackling social, health, environmental, and developmental issues in the Western World and the Global South. Importantly, participatory action research has mainly relied on methods such as surveys, interviews, storytelling, mapping, and deliberations, as well as alternative sources of knowledge, not the experimental methods used in the natural sciences. For example, in the

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[26] Haklay 2013, Strasser et al. 2018.

[27] Lewin 1946, p. 42.

[28] Freire 2000, Kindon, Pain and Kesby 2010, Gutberlet, Tremblay and Moraes 2014.

early 2000s, researchers from Rutgers University and the MIT have worked together with fishermen of the Northeast United States to produce an atlas of fishing communities and their territories. The atlas incorporated not only spatial information represented in traditional GIS systems, but also local and experiential knowledge of fishermen.[29]

At the other end of the spectrum, where scientists alone define the research agenda, one finds a vast array of "crowdsourcing" projects, some of which are cast as citizen science. The term "crowdsourcing", coined by journalist Jeff Howe in a 2006 *Wired* article, refers to an alternative to "outsourcing" for businesses. Instead of hiring a single company to perform a task, such as classifying a large number of user comments on a website, a corporation can divide the job into small tasks and offer it on a digital labor marketplace, like Amazon Mechanical Turk, for a "crowd" of individuals to perform against payment (or not). As Howe put it: "The labor isn't always free, but it costs a lot less than paying traditional employees. It's not outsourcing; it's crowdsourcing."[30] Crowdsourcing is the main mechanism behind citizen science data analysis projects, such as Galaxy Zoo. After computing and sensing, crowdsourcing (analyzing) represents the third largest community of participants in citizen science. Its high visibility in the media as well as its proximity to for-profit projects has fueled the criticism that citizen science may be exploitive and represent a form of digital labor.

A variety of other concepts and expressions, such as "amateur science" or "popular science" have been used to designate non-professionals engaged in science, but usually without producing novel scientific knowledge.[31] It is thus useful to keep these activities distinct from citizen science, action-based research, community research and others which focus on the production of scientific knowledge. These practices, increasingly subsumed under the heading of citizen science, have a long history which is as old as science itself.

3. A brief history of public participation in science

3.1 Amateur science in the 17th-19th century

When current advocates of citizen science don't describe their field as unprecedented (and as a result of the Internet), they often point to the nineteenth century as a time when citizen science

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[29] Kindon, Pain and Kesby 2010, ch. 7.

[30] Howe 2006.

[31] For a broad overview of science and its publics, Nieto-Galan 2016.

previously flourished. Charles Darwin, who toured the world on the Beagle from 1831 to 1836, is described as a prime example of citizen scientist since he carried out his research as an amateur without being paid by a scientific institution.[32] And yet, the results of his investigations were rather far reaching, since his publication *On the Origins of Species* in 1859 revolutionized our understanding of evolution to the present day. Yet, this historical narrative is misleading because it is meaningless to use the term "amateur" (as non-professional) before there were "professionals". If by "citizen scientist" we mean a non-professional who is active in scientific research and engages with professional scientists, there could be no "citizen scientist" before the mutually exclusive categories of "amateur" and "professional" were created. Before the late nineteenth century, almost all science was open to a vast range of practitioners and most "men of science" (and the few women) made a living through other means. Isaac Newton was Master of the Mint for the King in London and Antoine Lavoisier was administrator of the Ferme générale for the King in Paris. For a number of "men of science" research in the working of the natural world was only a part-time activity, in other words, a "hobby", although often a serious one. The long traditions of collective observation, specimen collections, and scientific prizes perfectly illustrate the workings of science before the professionalization of science.

The variety of people involved in the production of scientific knowledge, ranging across social hierarchies, professions, and occupation, is obvious in many examples of the collective study of natural phenomena. In several fields of natural inquiry, as early as the seventeenth century, it was common for scientific institutions to collect observations from a vast range of people residing in different places. Nowhere is this more evident than in the studies of the weather. The first scientific academies of the Scientific Revolution, the Academia de Cimento in Florence, the Royal Society in London, the Academy of Sciences in Saint Petersburg, all created networks of observers at a local, regional, or even global scale.[33] Most of these were short lived, but in the eighteenth century, more organized, standardized, and systematic networks were established. For example, in France the Société Royale de Médecine set up a network of physicians in the provinces to collect meteorological observations as well as observations of diseases. In Germany, the Societatis Meteorologica Palatina provided measuring instruments to regional observers as well as detailed instructions as to how to record

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[32] Silvertown 2009.

[33] Daston 2008, Rusnock 2002.

their measurements and observations of cloud cover and special meteorological phenomena.[34] These networks were composed of distinguished naturalists and physicians belonging to scientific institutions, typically provincial scientific academies across Europe, but also of a great variety of people mainly unconcerned with science, from naval officers to Jesuits and gentlemen to farmers. Since keeping a weather diary was a common hobby in the eighteenth century, it wasn't too difficult to recruit participants in these collective enterprises.

By the mid-nineteenth century, weather forecasting became of prime importance, especially for military campaigns. As a result, nation states established centralized weather forecasting services, under Urbain Le Verrier at the Observatory in Paris, Admiral FitzRoy at the Royal Society in London, and Joseph Henry at the Smithsonian Institution in Washington DC, collecting distant observation data, often sent by telegraph.[35] The fact that this specific mode of collective observation was so prevalent in the study of the weather is no accident. As soon as weather came to be considered not only as a local matter, but one involving regional or continental scales, understanding the weather, especially the origins of winds, required *simultaneous* observations in distant places. No single observer or observatory could perform this feat. And since weather was believed to have a significant impact on disease and character, in addition to playing a key role for navigation and agriculture, its study was a major topic of research throughout the history of science.

Collective weather observation served as a model for a number of other networks of observers. In his attempt to establish the impact of gravitation on ocean tides, Whewell created a wide network, comprising thousands of coastal observers in nine countries, on both sides of the Atlantic. In June 1835, during two weeks, seamen, port officials, residents, and local "men of science" (Whewell had coined the term "scientist" two years earlier, but it was not yet widely used) measured the water level every fifteen minutes, proving massive amount of data for Whewell's "great tide study".[36] A number of astronomical phenomena were similarly studied on the basis of observations provided by a large network of distant (lay) observers, from the meteor storm of 1833 to the passage of Halley's comet of 1835 (and 1910 and 1986). Even in the twentieth century, scientific institutions organized large-scale collective observations.

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[34] Kington 1974.

[35] Fleming 2000, Anderson 2005, Locher 2008, Vetter 2011.

[36] Reidy 2008, Cooper 2016a.

During the Cold War, Operation Moonwatch, starting in 1958, enrolled more than 750,000 volunteers around the world to track artificial satellites and help scientists understand their trajectories in the upper atmosphere.[37]

In natural history, especially plant and animal taxonomy and geology, the involvement of a broad range of practitioners was even more common than in the collective observations performed in meteorology and astronomy. From the sixteenth century, when naturalists such as Ferrante Imperato in Naples accumulated exceptional specimens in cabinets of curiosities, to the present day, when curators at natural history museums attempt to gather numerous specimens of each species, natural history has been a science of collecting.[38] Before the few professional naturalists could engage in the practice of "nommer, classer, décrire", as Georges Cuvier put it, they constituted large collections of specimens. Taxonomists, in botany as well as zoology, relied on broad networks of non-professional collectors, who were often experts in a taxonomic group or a specific location. Even in the nineteenth and early twentieth centuries, when natural history museums, such as the Museum für Naturkunde in Berlin, the Museum d'Histoire Naturelle in Paris, or the Museum of Natural History in London, mounted collecting expeditions to remote corners of their empires, collecting from local residents remained a major source of specimens for museum collections. Residents relied on their intimate knowledge of their local environment to identify specimens, which might be of interest to a distant collector often working in a museum located in a major city. Locals sometimes went beyond collecting specimens and gathered in clubs to produce new taxonomic knowledge. In early nineteenth century Britain, working-class artisans, relying on their specific observation skills as well as that of their familiar natural surroundings, met in pubs to discuss the specimens they collected and produced new taxonomic knowledge, which they shared with the scientific elite.[39]

Finally, another way to look into the socially very diverse kinds of people who participated in the production of scientific knowledge before professionalization is to look at the frequent prizes and contests set up by the academies of sciences since their creation. A standard way for the Academies, and the absolutist powers backing them, to find scientific and technical solutions to practical problems, was to offer monetary prizes for whoever could come up with

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37 Littmann 1999, McCray 2008.

38 Strasser 2012.

39 Secord 1994.

one.[40] In France, the *Academies des sciences* in Paris and numerous academies in the provinces challenged the public to find a solution to a great variety of problems. A jury made of academicians would then evaluate the anonymous submissions and decide if anyone was worthy of the prize. Sometimes, a distinguished academician won the contest; sometimes it was an unknown citizen. For the powers in place, the contest was also a way to spot talents and hire them as experts for the crown. In 1766, Lavoisier was just 23 years old when he won the prize (and a medal from the King) for having found an efficient way to illuminate the streets of Paris. This success launched his long career as an expert for the crown (and his beheading at the Revolution). The fact that anyone, provided they were literate, man or woman, noble or commoner, academician or artisan, could enter the prize, testifies to the view that expert knowledge was not restricted to formal qualifications or social distinction.

What these three examples show is that the intimate interweaving of popular and elite scientific practices was common in certain fields of sciences such as natural history, including botany, zoology, geology, meteorology, and astronomy. Expertise was not the monopoly of elite scientists, but was far more broadly distributed socially (though the access to resources, education, and appropriate networks played an important part in an outcome of elite capture of science). In natural history, the leading expert of a taxonomic group often was (and still is) a passionate amateur. In other fields, such as natural philosophy including the experimental and mathematical sciences, the production of knowledge rested on a narrower base, essentially gentlemen. However, even the elite practitioners were involved in a number of other activities, unrelated to science, for their patron or for the state, making them far less isolated from various societal concerns than the current professional scientist who often spends days, evenings and weekend in her laboratory. A second lesson from these examples is that the organizations who mobilized a broad public for scientific purposes often had another, more political agenda, in mind. From state building and the creation of an enlightened citizenry to the affirmation of state power over nature in distant colonies, the question of who produces scientific knowledge was (and is) intimately linked to the question of power and social order.

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[40] Caradonna 2012.

3.2 Professionalization of science, the laboratory revolution, and popularization

If the production of knowledge by heterogenous collectives was the norm for so long, at least in certain sciences, how did it become newsworthy in the twenty-first century to mention that amateurs participate in science? The short answer is that in the second half of the nineteenth century, the sciences have been deeply transformed through two processes: professionalization and the laboratory revolution. Both were responsible for creating (professional) “scientists” and “amateurs” as mutually exclusive categories. Thus, the very concept of citizen science, as a relationship between professionals and amateurs focused on the production of scientific knowledge only makes sense after these categories were produced, a process which took place during the nineteenth century.[41] With the establishment of numerous technical research and education institutions since the mid-nineteenth century (the *Eidgenössische Polytechnische Schule* was created in 1854, to become the ETH Zurich), the generalization of the German (Humboldtian) research university model, and the expansion of the role of research for industry and government, a number of professional positions were created for “scientists”. By the late nineteenth century, one could pursue research activities as a full-time occupation and earn a salary through it.

By the early twentieth century, the division between amateurs and professionals was well established, even if the extent of the interactions between these two social categories varied according to scientific disciplines. In the different fields of natural history, the relationships between them were still numerous, whereas in the experimental sciences, they were exceptional. In 1902, an editor for *Science* wrote about the decline in the number of local citizens attending the meetings of the British Association for the Advancement of Science: “It is becoming increasingly difficult to bridge the gap between the professional man of science and the amateur scientist.”[42] Even *Popular Science Monthly*, which did much to promote amateur scientists, recognized that same year that: “The era of the amateur scientist is passing; science must now be advanced by the professional expert.”[43] This divide contributed in no small part to shaping a literary genre: the popular science magazine. Journals such as *Popular Science Monthly* (since 1872) in the United States or *La Science et la Vie* (since 1913) in France took on the mission to bridge this gap between professionals and amateurs, while at the same

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[41] Mody 2016, Allen 2009, White 2016.

[42] Anonymous 1902a.

[43] Anonymous 1902b, p. 477.

time sustaining this division.[44] These journals created an imaginary public as unenlightened, but as one eager to learn about the wonders of sciences.[45] At the same time, they cultivated the domestic practice of science and technology, not for the production of new knowledge, but for education and amusement, essentially as a "hobby", a "*science amusante*".

It is useful to distinguish the "hobbyist" from the "amateur" in that, as the sociologist of leisure Robert A. Stebbins has argued, the hobbyist does not necessarily look up to the professional as a source of legitimacy, but pursues his or her hobby for its own sake. Hobbyists rarely aspire to contribute to the body of scientific knowledge, they simply want to exercise their science hobby and have fun. The amateur, on the other hand, draws from the norms and values of the professional and takes pride in his or her contributions to scientific knowledge.[46] The boundaries between these two categories are not insurmountable, as individual hobbyists have become amateurs when they became sufficiently self-confident in their scientific and technical expertise to contemplate contributing to the body of knowledge produced by professionals.

Scientific and technical hobbies have been numerous in the twentieth century, and blossomed after World War II, when the mass production of technical parts made them more widely accessible. In the mid-century, building radios, rockets and telescopes was a hobby for hundreds of thousands of Americans and significant, but smaller, numbers of Europeans. If they exercised their passion mainly alone, in their homes and gardens, they often gathered in clubs and were part of communities connected by hobbyist journals. These communities reinforced strong identities built around these technical hobbies at a time when the growing number of office jobs offered fewer opportunities for social and individual distinction. The technologies of the hobbyists were aligned with the great technological challenges of their days—home rockets at the time of the Apollo program—and sometime even relied on the exact same pieces of equipment, such as electronics components.[47]

Yet, the expansion of the hobbyist was not a spontaneous movement, propelled by the sheer curiosity of the middle class and its amazement about emerging technologies. For governments encouraged hobbyists to pursue their passion, especially teenagers and younger adults, as it

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[44] Bensaude-Vincent 2003.

[45] Bowler 2009, Lewenstein 1989.

[46] Stebbins 1992.

[47] Haring 2008.

constituted a way to develop technologies and professional skills that would be necessary for the state. The massive communication campaign, partially orchestrated by the German state, for the release of Fritz Lang's movie *Frau im Mond* in 1929, aimed at promoting amateur rocketry groups in Germany.[48] From them would perhaps rise the inventor that would help propel Germany into space. Similarly, after the World War II, the US Army strongly promoted amateur rocket building and edited manuals for a lay audience. In 1960, an Army instructor explained: "To support and maintain the rocket programs of the United States will require the best thinking of thousands of young scientists and technicians."[49] And it was precisely among the amateur rocket scientists that the United States was to find the workforce for its space program. The intended audience of the book was "the thousands of talented young people from among whom America must draw its scientists of the future." By supporting the hobbyists in their quest, governments gave them the impression of participating in the great scientific and technological projects of the days. But at the same time as these domestic technical hobbies were expanding, the public (mainly men) was increasingly excluded from the professional spaces where modern science was being carried out.

Hobbyists communities, composed of people who were commonly termed "enthusiasts" who cherished science and technology, represented increasingly important constituencies supporting the scientific enterprise. Given the sheer number of hobbyists and how they identified themselves with the latest "progressive" technology, a number of commercial companies specifically developed "kits" for them. Major corporations, such as Radio Corporation of America (RCA) and General Electrics (GE), developed entire lines of products specifically for the "ham radio" hobbyist, while other companies focused on a younger audience, especially through chemistry kits for boys (including the Gilbert U-238 Atomic Energy Lab released in 1950).[50] The popularization of technical tools and kits was part of a broader movement in society. In the postwar era, do-it-yourself home repair, for example, became an integral part of the identity of a middle-class man.[51]

Being able to rely on a broad public support for science and technology was crucial for Western democracies after World War II, as scientific research expanded dramatically. The atomic

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48 Neufeld 2013.

49 Brinley 1960.

50 Onion 2016.

51 Gelber 1999.

bomb, the radar, and penicillin, all developed during the war, had shown unambiguously that the fate of modern nations had become crucially dependent on scientific research. In the postwar social contract between science and the state, national governments gave researchers almost unlimited funding and freedom in exchange for the promise of technological benefits. The resulting rise of "big science" transformed not only the scale of the scientific enterprise, but also its nature, becoming a highly organized and professionalized institution with an extensive division of labor. The state increasingly relied on scientists for expert advice and enrolled them in vast numbers for military research. The public was cast in a role of consumer of scientific news and technologies and as a constituency of taxpayers that should support science enthusiastically.[52]

In parallel with the transformation of science into a professional activity the nature of scientific practices changed too. Whereas natural history was a dominant "way of knowing" nature until the nineteenth century, experimentalism grew as a dominant practice with the "laboratory revolution".[53] By the twentieth century, the experimental sciences, from physics to biology, redefined what "modern science" meant and occupied an increasingly large share of the research landscape. This shift in research practices had deep consequences on the involvement of the public in science. Indeed, the power of the laboratory has rested on its capacity to create a controlled environment from which credible witnesses could testify about the workings of nature. The exclusion of the public from the laboratory was thus key to its epistemic power.[54] As experimentalism became the dominant way of producing scientific knowledge, public participation in science declined accordingly.

The leading theoreticians of the scientific institution, from Robert Merton in the 1940s to Thomas Kuhn in the 1960s, have crafted a view of science as essentially governed by its own sets of norms and values. For Merton, scientists were driven by four key ideals (communism, universalism, disinterestedness, and organized skepticism) and for Kuhn, in *The Structure of Scientific Revolution* (1962), scientists were driven by values determined by their own community in a given paradigm. These conceptualizations of science reinforced the idea that

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[52] Lewenstein 1987.

[53] Cunningham and Williams 1992.

[54] Shapin and Schaffer 1985.

science was politically neutral and exterior to society (including the public), although it may be influenced (usually negatively) by it.[55]

3.3 Interfaces of dissent in the 1960s-1970s

In the 1960s and 1970s, the relationship between science and society was challenged from two overlapping, but different perspectives: the radical scientists movements, such as *Science for the People*, and the social movements, including the women's health and civil rights movements. After 1945, a small number of professional scientists, shocked by the use of atomic bombs over Japan, became outspoken critics of the use of science for military purposes. The Federation of Atomic Scientists, created in 1945 (renamed the Federation of American Scientists a year later), the Pugwash Conferences on Science and World Affairs (1957), and other organizations brought together scientists who were critical of the uses of science by the military. The physical chemist Linus Pauling, Nobel prize winner for chemistry of 1954, was an outspoken critic of nuclear weapon development, challenging a number of his distinguished colleagues, such as the theoretical physicist Edward Teller ("father of the H-bomb"). The petition he organized with his wife, signed by more than 11,000 scientists, including 54 Nobel Prize winners, led to the limited test ban treaty, banning atmospheric testing of nuclear weapons in 1963 (and the Nobel Peace Prize for Pauling).[56] These scientists and their organizations attempted to influence other scientists, shape science policy, and inform the public, but usually did not seek to expand public participation in scientific research.

In the late 1960s, radical scientists, including faculty and students, broadened the scope of their critique of science beyond the issue of atomic weapons and world peace. The publication of Rachel Carson's *Silent Spring* in 1962, pointing to the effects of DDT on wildlife, and other revelations about the impact of modern technology on the environment brought this issue on the agenda of radical scientists.[57] In the late 1960s, the eugenic potential of the new "genetic engineering" technologies as well as the expanded use of pharmacological drugs by psychiatrists broadened once again their critique of the impact of science on society. After 1965, students, and sometimes faculty, occupied research laboratories in universities, organized various kinds of protest at military recruitment offices on campus, or, in one of the

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[55] Merton 1979, Kuhn 1970, Hollinger 1996.

[56] Hager 1995.

[57] Egan 2007.

most dramatic events in the United States, bombed the military sponsored Math Research Center at the University of Wisconsin in 1970, leaving one researcher dead.

These protests were based on the idea that science did not serve the best interests of "the people", but those of the state and corporations (the "military-industrial complex"), or elite scientists themselves.[58] In 1969, American scientists, from Harvard and the MIT, created the group Scientists and Engineers for Social and Political Action, and begun publishing the newsletter *Science for the People*, which became the motto and the new name for the organization. The group challenged above all the belief in the neutrality of science and argued that the uses of science and technology deserved to be scrutinized in their political context. Their call was for a "radical redirection in the control of modern science and technology", away from government science advisors to the working scientists themselves. Although their actions were taken in the name of public interest, Science for the People made little efforts to include non-scientists in the discussions about the directions of scientific research, let alone the production of scientific knowledge itself. It was scientists themselves, who were to decide what was the public interest. In Europe, radical science movements called for a greater participation *within* academic institutions, creating councils where students, technical and administrative staff were represented, along with faculty. Organizations such as Science for the People in the United States, like other similar movements in France or the UK, also made great efforts to "educate the scientists" about issues such as the researchers working conditions, social inequalities, race, poverty and gender disparities.[59] The goal was to encourage the development of a community of "citizen scientists", scientists who thought of themselves as responsible citizens. As experts, members of radical science movements also attempted to inform the public about science and its social consequences through the organization of public conferences and the creation of editorial venues for science popularization.[60] Finally, a number of radical scientists were instrumental in the creation of a new field of "science studies", distinct from history and philosophy of science, and more attentive to the social role of science and to public understanding of science.[61]

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[58] Moore 2008.

[59] Debailly 2015, Quet 2013.

[60] Egan 2007.

[61] Debailly 2015.

Of far greater significance with regard to public participation were the various ways in which social movements of the 1970s attempted to involve lay people in the production of scientific knowledge. The women's health movements, in the United States and in Europe, sought to go beyond teaching women biomedical knowledge towards teaching women how to learn by themselves from their own bodies. This position resulted from their desire to "empower" women, but also, more pragmatically, because they believed that the available biomedical knowledge about women's health was not helpful in addressing their concerns. In 1975, for example, a group of women in Los Angeles carried out the Menstrual Cycle Study through collective and self-examination of their bodies. The results of their study made its way into *A New View of a Woman's Body*, a widely circulated textbook about women's health.[62] Similarly, civil rights movements, such as the Black Panthers in the United States, sought to involve African-American families in the production of knowledge about sickle cell anemia, a disease that was particularly prevalent in that community, and which had been somewhat neglected by the biomedical research profession.[63]

Even more visible in the media were the roles of residents in carrying out research about toxic waste and its effects on the health of their community. In the small town of Woburn, Massachusetts, for example, residents began to wonder in the 1970s if the cases of leukemia in children were related to the quality of tap water, which sometimes had an unusual olfactive and visual appearance. Mothers of sick children organized and conducted an epidemiological study about the prevalence of different health issues in their neighborhoods. Eventually assisted by researchers from Harvard, they were able to show that these health effects were most likely the consequence of a massive toxic waste release by a company in Woburn which had contaminated the water source. Residents engaged in a form of "popular epidemiology", combining experiential and expert knowledge, which allowed them to challenge the consensus view supported by state (and industry).[64]

But it was in the context of the AIDS crisis in the 1980s that it became most obvious how lay people could contribute in significant ways to the production of scientific knowledge. Members of Act-Up, an AIDS advocacy group, challenged how clinical trials for AIDS treatments were

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[62] Kline 2010, Murphy 2012.

[63] Nelson 2013.

[64] Brown and Mikkelsen 1997.

conducted. Speaking from their own experience as patients, but also as newly trained "lay experts" in the biomedical literature, they were able to overcome initial resistance from scientists and become partners in scientific research about their diseases. Since then, a number of other patient organizations, such as the The French Muscular Dystrophy Association (AFM) in France, succeeded in making the experiences and expertise of patients relevant for the production of biomedical knowledge.[65]

3.4 Interfaces of democratic deliberation in the 1980s

Knowing about the successes of grassroots organizations and lay people in contributing to scientific research in the 1970s and early 1980s, it may come as a surprise that the major policy shift with regard to the relationship between science and the public went into a very different direction in the 1980s. This shift was prompted by the multiple techno-scientific public controversies that erupted in that period and by a new understanding of the limitations of existing models of science communication. Controversies over such issues as GMOs, nuclear power, contaminated food and, later, nanotechnologies, were interpreted by natural and social scientists, policy makers, and the media as resulting from a "crisis of trust" between the public and science (*Section* 5.2). Science studies scholars felt vindicated because it confirmed their warnings about the shortcomings of the prevalent "public understanding of science" model. This model, which constituted the dominant view of the relationship between science and the public since at least the beginning of the twentieth century, construed the public as scientifically uneducated and its criticism of science and technology as resulting solely from its ignorance about scientific and technical matters.[66] Thus, the only way to ensure public support for science was to better inform the public about science and technology. This view of the public, later named the "deficit model", was the foundation of the flourishing science popularization industry and communication efforts of professional scientists of the postwar period.[67]

The new challenges to the authority of science questioned the assumptions behind the "deficit model" and led to a number of "institutional experimentations" aimed at restoring what was perceived as a faltering public trust in science.[68] "Participation" became envisioned as the cure

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[65] Epstein 1996, Rabeharisoa and Callon 2002.

[66] Lewenstein 1992.

[67] Callon, Lescoumes and Barthe 2001.

[68] Chilvers and Kearnes 2015.

for the problem of public trust in science. The meaning of “participation”, however, was not that of the social movements of the 1970s, but was cast more narrowly as participation in “decision making” about scientific research agendas or the implementation of technologies. This “participatory turn” based on a “deliberative regime”, was promoted by governments and international organizations in many areas of policy, not just science, as a way to strengthen (or restore) trust in public authorities and policy.[69] Consensus conferences, participatory technology assessment, and science shops became common formats, since the 1980s, for including citizens in the formulation of science policy and technological choices.

In consensus conferences, a small group of citizens are invited to deliberate about a controversial topic in the area of science, medicine, and technology. After receiving background information, they can ask questions to a panel of experts and then deliberate among themselves to produce a consensus document. Unlike in other forms of participatory democracy, such as public consultations through referendums, the goal is not to reach a decision reflecting the pre-existing majority opinion, but to produce a new consensus among the group that reflects the best scientific arguments, thus keeping in line with the idea that scientific issues are apolitical and should be evaluated on epistemic merits alone. Consensus conferences are thus also tools for educating the public and supporting the formation of a new public opinion.[70]

As scholars have pointed out, the problem with consensus conferences, as with many other institutional forms of deliberative democracy, is that key elements of the controversy may not be open for discussion. Crucially, the framing of the problem is usually decided by the organizers and cannot be challenged. In controversies about risks, for example, citizens can express their opinions about how new technologies should be regulated, but not whether they should be deployed at all. Consensus conferences follow the institutional agendas of policy makers and represent a form of “invited participation”. As sociologist of science Brian Wynn put it, “invited public involvement nearly always imposes a frame which already implicitly imposes normative commitments”.[71] A similar issue concerns the timing of consensus conferences in the process of policy making. Often, consensus conferences and other

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[69] Petersen 1984, Jasanoff 2003, Saurugger 2010, Bucchi and Neresini 2007.

[70] Wynne 2007.

[71] Wynne 2007, p. 107, Mahr and Dickel 2018.

deliberative mechanisms are “end-of-pipe”, i.e. they take place *after* most relevant decisions have been taken and there is little room left to significantly shape the outcome.[72]

Thus although these new participatory mechanisms were introduced as a new form of “public engagement with science” that would overcome the limitations of “public understanding of science”, in practice they shared the same assumptions about a deficient public, the value of progress, and the superiority of scientific knowledge.[73] For example, in 1995, Andreas Klepsch, a scientific officer of the European Commission’s Directorate-General XII for Science, Research, and Development, prefaced a volume on the “role of consensus conferences in Europe” by arguing that: “It is a fundamental *prerequisite* of productive public debate that the participants should share at least a measure of common knowledge and understanding.” But precisely what counts as “common knowledge and understanding” about a controversial issue, and even what the controversy is really about, was what should have been at stake in such a conference. Klepsch added that “scientists’ arguments and explanations are not widely understood by lay people; and at the same time, it seems that lay people’s legitimate interests and concerns are not generally appreciated by scientists”. By highlighting that scientists have “arguments and explanations” but lay people only “interests and concerns”, Klepsch reaffirmed the basic epistemic hierarchy that the participatory turn was meant to overcome.[74]

The (re)emergence of citizen science in the late 1990s can thus be understood as a generalization of a mode of interactions between science and the public that has been common for a long time in certain fields, such as astronomy and natural history. It can also be seen as a mode of public participation that promises to overcome the limitations of other modes, such as “public understanding of science” and “public engagement” by directly engaging with citizens in the research process. Citizen science, however, is not replacing these other modes, which remain active and well, but adds another dimension, particularly attuned to the current historical context.

Indeed, the rise (or the rediscovery) of citizen science reflects deep transformations in Western societies, such as the democratization of education, the strengthening of direct democracy, and the growing modernist reflexivity. The democratization of education, especially higher

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[72] Jasanoff 2003.

[73] Wynne 2006.

[74] Joss and Durant 1995.

education, after the end of World War II,[75] has produced unprecedented numbers of citizens with high levels of scientific education (over 43% of 24-34-year-olds in OECD countries had completed tertiary education in 2016).[76] As a result, there are today many more citizens who are not professionally engaged in scientific research, but have the background to engage in scientific research and to question the discourses of professional experts (*Section* 6.2). Similarly, the proliferation of (new) social movements since the 1960s reflects, and at the same time fuels, stronger demands for more "direct" forms of participatory democracy. Some grassroots citizen science initiatives are an expression of this, where the distrust of "professional" politicians is replaced by the distrust of professional experts. Oddly, these forms of dissent become sometimes aligned with current populist movements who express distrust of both, as the initial quotes of this report make clear. And like participatory democracy, participatory science can be both empowering and disempowering, depending on the actual power relationships between the partners (*Section* 4.3).[77] Finally, the rediscovery of public participation in scientific research, and more specifically in the idea that *every* citizen should explore scientifically the world around him or her, reflects what sociologist Ulrich Beck has called the "risk society", with its exacerbated reflexivity and anxiety about the consequences of modernity.[78]

If citizen science will fulfill its scientific, educational, and democratic promises, history can't tell. But this short overview of how science and the public have interacted over the past centuries should give indications about some of the possible futures of citizen science. The next section will outline different ways in which citizen science projects have engaged with participants and how they have envisioned different kinds of citizens.

4. Politics of participatory interfaces

4.1 Serious gaming and gamification

Promoters of citizen science projects have adopted a number of different interfaces to enroll participants in scientific research. Particularly important for online projects, the concept that the activity needs to be considered as a game is a useful demonstration for the way some project

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[75] Barro and Lee 2013.

[76] OECD 2017.

[77] On the case of France, see Mazeaud and Nonjon 2018.

[78] Beck 1992.

designers perceive the motivations, interests, and reasons to participate in a citizen science project.

By definition, participation in citizen science is a leisure activity—it is done as a volunteering activity at times that are free from commitment to employment. Therefore the activities fall under the definition of "serious leisure", which is "the systematic pursuit of an amateur, hobbyist, or volunteer core activity that people find so substantial, interesting, and fulfilling that, in the typical case, they launch themselves on a (leisure) career centered on acquiring and expressing a combination of its special skills, knowledge, and experience".[79] Because of the association of games with leisure activities, some concepts about gaming have been used to attract people to join and sustain their participation in citizen science activities. The process of enticing people to use computer systems through the application of game mechanisms is a more general trend in computing known as "gamification."[80]

In fact, full-fledged computer games in which the activities of the participants are linked to citizen science are very rare. The Swiss physicist Bernard Revaz who suggested the creation of a "Massive Multiplayer Online Science" (MMOS) developed one such example. Instead of "gamifying" a scientific research task, it was embedded in a popular online role-playing game, EVE Online. In this science fiction-themed game, there are around 50,000 players connected at any given time. Around 1% has entered a virtual space to classify elements from the human protein atlas or images of potential exoplanets, a fitting theme given the narrative of the game.[81] As for many online games, the EVE Online players have created numerous communities and the MMOS team has attempted to attract players to a community devoted exclusively to science. However, as the main goal of the participants is to play the game, it is unclear to what extent they might be willing to perform scientific tasks that are unrelated to the game narrative and reward system over an extended period of time.

Much more common is the use of game-like features within the design of citizen science activities, especially when they are carried out online.[82] The prime examples are Foldit and EyeWire, game-like online environments in which participants are asked to predict the three-

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[79] Stebbins 2017, p. 5.

[80] Jennett and Cox 2018.

[81] Ascension http://mmos.ch/news/2016/11/15/ascension.html (accessed, 2.3.2018).

[82] Schrier 2016.

dimensional structure of proteins and map neurons networks in the brain, respectively. These are sometimes termed “games with purpose” or “purposeful games”.[83] While their developers promote these activities as games, their participants often point to the fact that they are not necessarily enjoyable, and that the motivation to support the scientific effort is more central to their efforts. At the same time, the use of game-like elements (points, badges, levels, etc.) have been shown to be useful elements to sustain participants activity over long periods of time or to stimulate focused efforts at a given time. Some organizers of citizen science projects such as Chris Lintott, founder of the Zooniverse platform, have resisted any forms of gamification preferring to focus the participants’ attention on the scientific task. But in other cases, including on the Zooniverse platform, it was the participants who introduced game-like features, such as leaderboards.[84]

A comparative study of two types of games that are aimed at classifying moths, a relatively unattractive species, highlighted some of the potentially negative side-effects of gamification. One of the games, Happy Match, was mostly focused on the science task, while the other, Forgotten Island, focused on a general game, where the science tasks were embedded in the game progression. The results of this comparison showed that the game narrative helped engage participants and that the quality of the data was high in both scenarios.[85] However, when the game was the main task for the participants, researchers observed evidence of “cheating” and participants trying to minimize the effort on the scientific task.

The evidence that is emerging from the gamification of citizen science projects points to a gap in perception between the designers and project initiators, who are usually from the technological and scientific world, and their participants who have more diverse backgrounds. For the designers, a game or “fun” activity is central to how they conceive of a leisure activity that will sustain them over time. On the other hand, some participants are showing ambivalence to the description of scientific activity as mostly fun or a game, because their motivations and effort to do the work well is more related to how they value the scientific output rather than how much fun they have playing the game. Importantly, much more nuanced insights on the

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[83] Iacovides et al. 2013.

[84] Eveleigh et al. 2013, Greenhill et al. 2014.

[85] Prestopnik, Crowston and Wang 2017.

advantages and disadvantages of gamification have emerged in the literature,[86] for example, on their impact on different groups of participants.[87]

4.2 Smart crowds and crowdsourcing

While "serious games" or "games with purpose" are emphasizing that citizen science is a leisure activity and showing a framing that prioritizes hedonistic motivations of participants and the need to entice them to the project and maintain their engagement through the notion of play, the framing of participants as a "crowd" and the use of crowdsourcing concepts is pointing to the world of work and labor. In his original definition of crowdsourcing, journalist Jeff Howe focused on the way technology changed the practices of companies in solving business problems. A more general definition for the purpose of citizen science is provided by communication scholar Daren C. Brabham: "Crowdsourcing is an online, distributed problem-solving and production model that leverages the collective intelligence of online communities to serve organizational goals."[88] In this framing, the organization, which can be a scientist or a group of researchers, reach out to a wider group of participants to solve a scientific problem.

Linked to the practice of crowdsourcing is the popular idea of a "smart crowd", which actually covers distinct concepts. Multiple participants can analyze information independently of each other and provide a form of replication study for the results. More interestingly, scholars have claimed that when a group of people independently make an estimate, for example the number of marbles in a jar, their collective evaluation is superior ("smarter") that that of most individuals and even most "experts". James Surowiecki used this example to argue that crowds exhibited more "wisdom" than individuals.[89] In other situations, participants may discuss among themselves which may lead to self-organization, for example when a group of participants have to map an area after a disaster and split the work among themselves. Finally, there can be situations in which participants form groups, consult with each other, and engage in a process of collective learning to solve a problem, such as the Foldit teams routinely do.

Scientific organizations may have different kinds of "problems" for which crowdsourcing might look like an attractive solution. The problem can be one of limited resources such as

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[86] Jennett and Cox 2018.

[87] Bowser et al. 2013.

[88] Brabham 2013, p. xix.

[89] Surowiecki 2005.

computing power to process information, human power (time and attention of PhDs) to analyze data, or simply funding to pay people and buy equipment (this specific case of crowdsourcing is called "crowdfunding", *Section* 8.2). The problem can also be one of geographic distribution, for example when ornithologists want to understand bird species distribution in Switzerland, which is virtually impossible without the help of observations from local participants across the country. A variant of the geographic distribution challenge is access: ordinary people's backyards are actually some of the most inaccessible places for scientists due to the transaction costs of gaining a permission to access them and use them for environmental observations.[90] The problem can also be one of ideas and disciplinary knowledge, for example when scientific organizations need to solve complex interdisciplinary problems, which require contributions from people from a different disciplinary environment. This is also common in mathematical problem solving, where experts with knowledge of different sub-disciplines, collaborate together to develop a new solution to a problem.

Therefore, crowdsourcing is capturing a wide range of activities in the field of citizen science –especially in projects where a very large number of participants is involved. Another important concept that is linked to crowdsourcing, but has special relevance to citizen science is legal scholar Yochai Benkler's idea of "commons-based peer production" systems.[91] In such systems, the "inputs and outputs of the process are shared, freely or conditionally, in an institutional form that leaves them equally available for all to use as they choose at their individual discretion". The emergence of free/shared software in the early days of the Internet is an example of such a system and its generalization makes it central to the idea of "open science". It is important to consider the critiques of crowdsourcing—most importantly, the emphasis on the power and economic relationship between the people who run the process and participants, even in the case of commons-based peer production. Some participants will have more ability to use the output of the system for their own benefit—because they have the technical skills, resources, and interest—while others will not gain anything from the collective effort, and thus will not receive any substantial reward for their work.

Crowdsourcing of classification tasks, however, might only be a transient form of public participation in science. Indeed, classifying the shape of galaxies or counting the number of

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[90] Cooper, Hochachka and Dhondt 2012.

[91] Benkler 2006.

penguins on a picture mobilizes relatively low cognitive abilities. In their recommendations for new crowdsourcing projects, the organizers of Zooniverse, the main crowdsourcing platform for science, point out that “Ideally, a 10- or 12-year-old child should be able to understand and do your project.”[92] But the same basic tasks are also ideally suited for machine learning approaches, especially when large data sets have already been classified by humans. For this reason, crowdsourcing projects, such as Galaxy Zoo, have attracted much attention among computer scientists who want to automate classifications tasks.[93] Kevin Schawinski, the co-founder of Galaxy Zoo, outlines his vision as “the work of citizen scientists taking part in Galaxy Zoo points to a future where machine learning and humans both contribute to systems capable of analyzing extremely large data sets”.[94] This could mean that crowdsourcing with humans will only be necessary to the extent that it provides a large enough data to train machine learning algorithms. Crowdsourcing projects could turn to cognitively more complex tasks, that machine learning cannot (yet) tackle, but these projects will then lose the broad accessibility which now explains their success and become reserved to participants with a high level of expertise or ready to commit a significant amount of time to acquire the necessary training.

4.3 Grassroots organizations

The final framing that is relevant only to some citizen science projects is one that emphasizes citizen empowerment through the practice of science (see also *Section* 3.3 and the discussion of civic science). We can differentiate between two types of grassroots organizations: the first (e.g. a local bird watching club) is set to focus on a scientific issue and positions itself mostly as apolitical, although under some conditions, such as when a new development threatens a local habitat it can become politically active. The second (e.g. an environmental advocacy group) is linked to issues of environmental and social justice and mobilizes scientific evidence to support its cause. Interestingly, the framing of science as disinterested, objective, apolitical, and universal, is often being used by these organizations to make claims about the power of the evidence that they have collected.[95]

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[92] https://www.zooniverse.org/lab-best-practices/great-project (accessed, 19.3.2018).

[93] Hocking et al. 2018.

[94] Schawinski 2016.

[95] Kullenberg 2015.

The first type of grassroots organizations is particularly important in traditional areas of recording ecological observations with local groups that organize themselves around a topic of interest. For example, the UK Glowworm Survey is an organization that gathers people with interest in glowworms across the UK and collects reportings of these charismatic insects. The organization is run by amateur naturalists who collect the information, organize it, share it among themselves, and study the insects. They use the services of the Biological Records Centre (a government-funded body that supports amateur naturalist societies and individuals across the UK) and are willing to share their extensive knowledge and expertise with scientists, although their studies are self-directed and controlled by each member of the group according to their specific interests. Similar ad-hoc, grassroots organizations that attracted much more attention recently are people who are interested in DIYbio (Do-It-Yourself biology) and are organizing themselves in "biohacking spaces" to explore different projects related to biotechnology. As in the case of the amateur naturalists, they are emphasizing their interest in scientific exploration, playfulness, or artistic applications of biotechnology.[96] As the organizers of the DIYbio laboratory Genspace, in Brooklyn, NY, put it: "Remember when science was fun? At Genspace it still is."[97]

The second type of grassroots organizations is more contentious in the scientific framing since it is overtly linked to local activism. In environmental justice cases, the main claim that the members of the organization make is about the distribution of environmental burden across space, and especially about its impact on marginalized and disempowered groups. Since environmental regulations are based on scientific metrics (for example the EU has strict regulations on the levels of NO_2 in cities), there is a need for empirical evidence for a claim to stand. Thus, groups that are engaged in environmental justice struggles are frequently using citizen science in their activities (although it is frequently termed "civic science" or "community science" as we've seen above). An example for such an effort emerged with the Global Community Monitor—an organization that, since 1998, has developed a method to allow communities to monitor air quality near polluting factories.[98] Members of the affected community using a technique that is affordable and accessible perform the sampling—widely available plastic buckets and bags followed by analysis in an air quality laboratory. This allows

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[96] Delfanti 2013, Davies 2017.

[97] Genspace.org, 2009, available at Internet Archive Wayback Machine: https://www.genspace.org/ (accessed, 2.3.2018).

[98] Scott and Barnett 2009.

data collection at the exact time when community members notice (or smell) an activity in the factory that they suspect is unlawful. Finally, the community is provided with guidance on how to understand the results. This activity is termed “Bucket Brigade” and is used across the world in environmental justice campaigns, for example in the struggle of local African-American residents in Diamond, Louisiana against a polluting Shell Chemical plant.[99]

Such activities are happening at different scales, and do have their more technologically focused form. The Public Laboratory of Open Technology and Science, best known as “Public Lab” and now based in Cambridge, Massachusetts, is a community of environmental activists and technology experts that promotes the use of low-cost adapted (“hacked”) technology to monitor environmental issues.[100] One of their early efforts, following the 2010 Deepwater Horizon oil spill, was the creation of an aerial imagery apparatus using a kite or a balloon carrying a cheap digital camera to support a “participatory mapping” effort of the oil spill on the Louisiana coast. The images that the camera captured are then sorted and stitched together to create a continuous image over the area where the balloon or kite has flown. This large-scale imagery provided visible evidence that was then annotated with additional information to highlight specific community issues.

In other cases, this system has been used to provide evidence on how many participate in public demonstrations, or on the impact of a new road on a Palestinian village in Jerusalem. In Public Lab’s work, affordable technology is combined with community expertise and work to inform a situation of local concern. In such situations, citizen science is a tool of empowerment in the political sense, as it provides “hard evidence” that emerges from scientific instruments or sensing devices, and methodology which supports a specific narrative that is of importance to the people who put it forward, and is also accepted as a form of evidence for policy. This approach has been viewed with suspicion by some professional scientists who assume that activism is contravening the expectation of disinterestedness in science and may produce biased data (see *Section* 5.1). Another cause of concern is raised by activists themselves, who argue that by adopting a strategy of counter-expertise, activists may lose their independence because they have to adopt the framing of the issue as well as the technical norms inherent to scientific measurements that are imposed by governmental regulatory bodies. In other words,

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[99] Ottinger 2010.

[100] Dosemagen, Warren and Wylie 2011.

they fear that invitations issued by governments to participate in counter-expertise may be a tool to govern the critique of technology.[101]

5. Scientific promises

5.1 Is citizen science good for science?

Advocates of citizen science highlight its contribution to three main areas: science, education, and democracy. A dominant view among organizers of citizen science projects is that it should primarily serve scientific goals and that its value should thus be determined by professional scientists (this is articulated in ECSA's *Ten Principles* as "genuine science outcome"). Measured in this way, citizen science has significantly contributed to the advancement of science. By January 2018, the data collected through the eBird project (sensing) resulted in over 150 peer-reviewed publications and the Zooniverse projects (analyzing) have resulted in over 120 peer-reviewed publications (not including meta studies, i.e. publications about Zooniverse or eBird projects).[102] Some of these publications have appeared in leading scientific journals and been widely cited in the scientific literature.

For example, astronomers and founders of Galaxy Zoo Chris J. Lintott, Kevin Schawinski, and co-authors (including over 100,000 volunteers), authored a paper on galaxy morphologies, which was published in the *Monthly Notices of the Royal Astronomical Society* and received over 850 citations. The contributions of players who analyzed electron microscopic images of neurons on the project EyeWire to understand how "the mammalian retina detect motion" resulted in a publication in *Nature* where the "EyeWirers" were included as co-authors. Similarly, the scientists and players of Foldit published a paper in *Nature Structural & Molecular Biology* where they presented a new solution for the structure of a specific protein, which they had been unable to solve through automated methods.[103] The fact that citizen science projects have resulted in widely cited publications in high-profile scientific journals and that the contributing citizen scientists were often included as co-authors clearly demonstrates that citizen science can contribute to the scientific enterprise as currently understood by scientists.

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[101] Pestre 2011.

[102] http://ebird.org/content/ebird/science/publications/ (accessed, 15.1.2018), https://www.zooniverse.org/about/publications (accessed, 15.1.2018).

[103] Kim et al. 2014, Khatib et al. 2011.

Organizers of citizen science projects often highlight that professional scientists alone could not have reached the scientific results without the collaboration of citizen scientists. Indeed, the main scientific results of citizen science projects have relied on massive data analysis or collection on a very large scale (Galaxy Zoo planned to classify one million galaxies). Mostly, the achievements of citizen scientists were not due to their special cognitive or perceptual qualities, but merely to the scale at which they could be mobilized and the resulting amount of labor they contributed collectively. However, several successes of citizen science projects also highlight the contribution of individual citizen scientists. Famously, Hanny van Arkel, a school teacher from the Netherlands participating in Galaxy Zoo, noticed on an image an irregular blob next to a galaxy. Instead of interpreting it as background "noise", she drew the attention of the volunteer community and professional astronomers to this anomaly, which was eventually confirmed to be a new kind of stellar object, named Hanny's Voorwerp. Within weeks, Hanny van Arkel noticed another unusual feature on an image, which turned out to be a new class of galaxies, "green peas".[104] Similarly, in the protein-folding project Foldit, some players have developed exceptional skills at solving three-dimensional structures and contributed to solving difficult scientific problems.

One of the most extensively studied aspects of citizen science is the question of data quality. Indeed, at first sight, it might seem surprising that research performed by "citizen scientists", which may have no formal training in science, could produce reliable scientific data. The fact that trust in scientific data rests not only on sound methods, but also on the credibility of individual scientists and institutions, make the evaluation of citizen science data difficult when it is associated with large collectives of people with unknown credentials. It is more useful to reframe the question "can citizen *scientists* produce reliable data?" to "can citizen *science* produce reliable data?" since knowledge is always produced collectively. The short answer is simple. Even though no definitive number exists, one can estimate that over one thousand peer-reviewed papers have been published resulting from citizen science projects, many in highly selective scientific journals. Thus, by the criteria set by the scientific community, citizen science does produce reliable scientific knowledge.

The more detailed answer is provided by the studies that have focused on data quality mechanisms in citizen science and specifically on whether citizen scientists produced data of

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[104] Straub 2016.

the same quality as experts.[105] For research practices as different as biodiversity data collection and cancer images analysis, these studies have found that “volunteer data are not consistently more variable than expert data”.[106] One possible explanation for the concern about data quality is that citizen science requires an approach to the design and implementation of “quality assurance” procedures, which are apparently different from those used within institutional laboratories or in common top-down highly controlled industrial processes. In order to insure data quality, citizen science organizers have developed specific mechanisms. One study identified as many as 18 different data validation mechanisms in citizen science research.[107] The four most important include: 1) extensive replication by multiple participants, 2) rating of participants according to the past performance of data accuracy, 3) use of instrumental evidence, and 4) expert review of the data.

These four mechanisms also exist in academic science, but are often implemented differently. First, although replication forms a cornerstone of scientific methodology, in practice it is rarely carried out.[108] But for citizen science projects, especially online, since there is often an excess of participants for the tasks and that participants’ labor is essentially free, projects scientists can replicate data analysis on a scale rarely attained in academic science. Second, in academic science, the individual credibility of researchers plays an important part in the evaluation of their data, as sociological studies of scientific practice have amply shown.[109] However, no formalized and transparent system exists, like in citizen science, for rating individual trustworthiness. Third, calibration and automatic instrumental evidence (metadata) are also common in many scientific fields, and are used in citizen science—for example in automatic timestamp and location that is associated with an image captured by a mobile phone. Finally, expert review is practiced at all stages of knowledge production in academic science, especially in the publication peer-review process. However, peer-review, as currently practiced, is not without its problems, and has been criticized as a less-than-perfect system for ensuring data quality in science. The attempt by certain citizen science projects to improve peer-review, along

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[105] Cooper 2016b.

[106] Turnhout, Lawrence and Turnhout 2016, Candido dos Reis et al. 2015.

[107] Wiggins et al. 2011.

[108] Baker 2016.

[109] Collins 1992.

the line of “open review” for example is thus aligned with the current evolution of academic science.

One issue about data deserves special attention since it frequently comes up in discussions about the value of citizen science for producing scientific knowledge. Participants classify images of galaxies, for example, with different levels of accuracy, which may reflect individual perceptual or cognitive biases. But nobody would suspect that they reflect *political biases*. This is not the case for the production of environmental data, for example, or any kind of data of immediate practical importance. In 2015, an editorial in *Nature* noted “the potential for conflicts of interest” in citizen science, adding that one “reason that some citizen scientists volunteer is to advance their political objectives”.[110] The editorial prompted a pointed response from the European Citizen Science Association, the Citizen Science Association and the Australian Citizen Science Association, which argued “traditional science also struggles with issues related to transparency of motives, conflict of interest, and integrity. Citizen science is not special in this regard.”[111]

The debate about the trustworthiness of citizen science data mirrors an earlier conversation about Wikipedia, the open online encyclopedia launched in 2001. After a stream of criticism, especially from academics, challenged Wikipedia on the basis that the authors of the articles were anonymous, and thus potentially unqualified, unreliable, and unaccountable, the journal *Nature* asked experts to compare articles in Wikipedia and in the *Encyclopædia Britannica*. The results, published in 2005, showed that the error rate was equivalent in both encyclopedia. Although the study contained a number of methodological flaws (as pointed out by editors of the *Encyclopædia Britannica*, but challenged by the authors of the study), the prestige and visibility of *Nature* contributed to making this study a turning point in the debate about the reliability of Wikipedia, which is hardly questioned today.[112] Although the reliability of citizen science data is still debated, it seems likely that it will follow the same path as Wikipedia. Yet, we can expect to see a major difference—the lost faith in the *Encyclopædia Britannica* might be the basis of concern by scientists and professionals that the anonymous crowd will replace them and obviate their hard earned position. But across the spectrum of citizen science, we can

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[110] Anonymous 2015a.

[111] Newman, Roetman and Vogel 2015.

[112] Tkacz 2015.

see a clear role for the professionals in organizing and managing the data, analyzing the results, or publishing academic papers (which participants are less interested in). This points towards more symbiotic relationships between scientists and the public, instead of replacement. There is little, if any, empirical support for the claim of political scientist Philip Mirowski that “citizen science is fueled by the fact that the public sector is trying to get out of the science business” and that paid scientists are being replaced by free citizen scientists.[113] Overall, citizen science can not replace the professional “science business” on a significant scale, because citizen science will ever only be suited to a small area of the current scientific research enterprise.

Citizen science has also made a different kind of contribution to the scientific enterprise through the development of new, low-cost, and open-source technologies. By idealism and out of necessity, participants in do-it-yourself (DIY) laboratories have developed cheap alternatives to standard laboratory equipment, such as the Open PCR (a common tool to amplify DNA), which costs around $600 instead of a $6,000 for a commercial equivalent. Sometimes, these open source instruments have offered new capabilities, such as the microfluidic device developed by a group of biologists and DIY enthusiasts at the MIT, which allows automated experimentation with small volumes of liquids.[114] Other examples include the development of devices for environmental monitoring, such as the open radioactivity detectors developed by the NGO SafeCast in the wake of the Fukushima Dai-ichi nuclear reactor disaster in 2011 to allow citizens to map radiations.[115] Such efforts have been supported internationally by the Gathering for Open Science Hardware (GOSH), which met for the first time at CERN, in Geneva, Switzerland in 2016.[116] Five years earlier, CERN had launched the first Open Hardware License (OHL), in order to encourage the development of open hardware and provide an alternative to patents. Although the main drive behind these open hardware projects has been to lower the barriers to entry to scientific research for citizens, it has also brought these new open technologies into mainstream scientific laboratories.

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[113] Mirowski 2017.

[114] Kong et al. 2017.

[115] Brown et al. 2016.

[116] Gibney 2016, http://openhardware.science/ (accessed, 2.3.2018).

5.2 The crisis of expertise

One of the most cited benefits from citizen science for the scientific enterprise is its contribution to fostering public trust in science. Unlike previous public engagement initiatives, which attempted to achieve the same goal by implementing a “two-way dialogue”, citizen science aims at “co-producing” knowledge between science and citizens. The recognized limitations of “public dialogue” methods (*Section* 3.4) have made citizen science a particularly attractive alternative for science policy administrators (even if educational studies have only provided limited evidence so far that participation in citizen science projects actually does increase public trust in science, see *Section* 5).

But before asking if citizen science can help restore trust in science, one should critically assess if there is such a thing as a “crisis of trust”. A number of accounts, by scholars and journalists, highlight four kinds of events that have undermined blind confidence in science and scientific and technical experts: first, the industrial accidents, from Three Miles Island (1979) to Chernobyl (1986) and Bhopal (1984) to Deepwater Horizon (2010); second, the health scandals such as HIV-contaminated blood (1980s-1990s) or mad cow disease (1990s); third, the cases of misconduct in science especially related to conflicts of interest with industry; and, finally, the rise of populist discourses, disregarding professional expertise as exemplified by the positions of the Trump Administration on climate change and numerous other issues. All of these factors are plausible explanations for a crisis of expertise, but they establish neither its existence, nor its novelty.

A received view about the history of public participation in science places the beginnings of contestation of science and technology, and of a so-called “crisis of expertise” during the counterculture movements of the 1960s, following a period of supposedly uncritical enthusiasm for science and technology during the “*Trente Glorieuses*” (1945-1975). Yet as recent historical scholarship shows, contestation has much deeper roots. From doctor’s resistance to smallpox vaccination in the eighteenth century to the destruction of weaving machines by textile artisans and the protests against the environmental consequences of the early chemical industries in the nineteenth century, the introduction of numerous technologies were often met with fierce opposition and framed in terms of sanitary and environmental risks long before the twentieth century.[117] Even at the heart of the "*Trente Glorieuses*", numerous citizens resisted the view that science and technology would necessarily lead to a better life.[118] They revolted against the effects of factories on air quality (the Great Smog of 1952 in London was estimated to have killed prematurely 4,000 people in four days) and water quality (which led to the decrease in eatable fish in urban rivers). In France, civilian nuclear power (and not just "the bomb") was a key factor, since the early 1950s, in mobilizing the public against a major scientific and technological development.[119]

Even though the "crisis of expertise" is not new, it might be reaching an unprecedented level. But opinion polls give a different picture. The University of Chicago's General Social Survey of the American public's opinions indicates that the "confidence in scientific community" has been stable since 1970, with 40% expressing "a great deal" of confidence and less than 10% "hardly any". For several other institutions, such as "medicine", the "press" or "Congress", public trust has strongly declined in the same time period. In 2018, trust in the "scientific community" was higher than for any other institution, except the "military", including "organized religion", "major companies", and all branches of the federal government.[120] Other American polls paint a similar picture. The NSF's historical survey of public attitudes about science and technology indicated that around 70% of respondents believed that the benefits of scientific research outweigh harmful results, and that figure has not changed between 1979 and 2016.[121] The situation in Europe is no different and, as *Nature* noted, based on a 2015 poll by the Royal Society of Chemistry, "the public trusts scientists much more than scientists think".[122] The question of whether citizen science can contribute to restoring trust in science is rather moot if there is no evidence of a general "crisis of expertise," except in the imagination of experts.

The appeal to an imaginary "crisis of expertise" is, however, revealing a deep-seated assumption about the relationship between scientific evidence on the one hand, and individual opinion, behavior, or public policy on the other. The fact that consumers avoid buying GMO

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[117] Jarrige 2016, Fressoz 2012.

[118] Pessis, Topçu and Bonneuil 2013.

[119] Topçu 2013.

[120] General Social Survey, https://gssdataexplorer.norc.org (accessed, 2.3.2018).

[121] National Science Board 2016, ch. 7.

[122] Anonymous 2015b, Bauer, Shukla and Allum 2012.

food (or that oncologists smoke cigarettes) does not mean that they distrust scientific evidence showing that GMO is safe for their health (and smoking is not). Interpreting individual choices, as well as public policies that do not follow scientific evidence as resulting from a "crisis of expertise" amounts to evacuating the political (or moral) dimension of any such decision.[123] Although there is little evidence for a "crisis of trust", the public's criticism of science and technology might have taken a new form. The increased level in education, and especially higher education, across advanced economies, combined with increased (open) access to scientific publications, made the public criticism much more informed and difficult for experts to brush aside.

5.3 Changing the research landscape

Evaluations of the impact of citizen science on scientific research often assume that research is a zero-sum-game, i.e. that the research tasks performed by citizen science would otherwise be performed by research organizations. Citizen science would thus not change the extension of the research landscape, i.e. what areas of the natural and social worlds are being investigated. However, there is strong evidence that this is not the case. A significant amount of citizen science, especially with regard to biodiversity surveys, performs research that would not be carried out otherwise, but nevertheless be considered valuable scientific research. In some areas of biodiversity surveys, citizen science contributes the vast majority of taxonomic data submitted to the professional Global Biodiversity Information Facility (GBIF).[124] But citizen science has also carried out research on topics that would be considered of limited scientific interest. In both cases, citizen science is changing the boundaries of the research enterprise.

More fundamentally, some commentators have asked whether public participation in research could change how science is done at a deeper epistemic level. Since the 1970s, feminist scholars have questioned the gendered assumptions embedded in scientific methodologies and called for a broadening of the epistemic norms of what counts as "good science". Molecular biologist and feminist philosopher Evelyn Fox-Keller, for example, showed that the research performed by the geneticist Barbara McClintock was not based on a standard approach of "detached" objectivity, but on the idea that researchers should also "feel" how organisms (in her case corn) live and react to changes in their environment. Fox-Keller argues that this

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[123] Sarewitz 2015.

[124] Chandler et al. 2017.

epistemic stance was crucial for the success of McClintock's research, for which she received the Nobel prize in physiology or medicine in 1983. Other scholars have drawn attention to the importance of "experiential knowledge", "embodied knowledge", "situated knowledge", or simply "lay" knowledge for the pursuit of science.[125] The importance of these alternative epistemologies may vary by scientific field, and are likely to be more relevant for research on human health or the local environment, than on distant galaxies. However, even in this field, as the example of Galaxy Zoo shows, the human skills that allow participants to make a scientific contribution are not solely cognitive but also personal and perceptual. Similarly, an editorial in *Nature* described the protein-folding project Foldit, as "Science by intuition".[126]

There is a tension running through participatory projects between those who aim to turn citizens into "orthodox" scientists and those who hope to change what "orthodox" science means. For the latter, the norms of *what* counts as scientific knowledge is intimately tied to *who* can contribute to science. They argue that it is only by including other forms of knowledge (lay, indigenous, experiential), as outlined above, that science will become more inclusive and a better science. The argument was made most forcefully by the women's health movements in the 1970s, when they claimed that lay women could, through collective self-examination and sharing of personal experiences, produce new *scientific* knowledge about the female body as sociologist Michelle Murphy shows convincingly (see *Section* 3.3).[127] Indeed, their inquiries led to a better understanding of the biology of the menstrual cycle, for example, and to the publication of a women's health manual that was unchallenged by the medical profession. In a very different area, sociologist Brian Wynne showed that after the Chernobyl accident, British government experts argued for restrictions on sheep grazing, based on their scientific assessment of radioactive fallout and ignoring lay knowledge of farmers, which contradicted their own. But it turned out that the farmers were correct in their evaluation (the radioactivity came from the nearby Sellafield nuclear power plant) and including their lay knowledge into risk assessment would have led to a more robust scientific expertise.[128] Wynne's study also

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[125] Keller 1983; on "experiential knowledge", Smith 2006, Harkness 2007; on "embodied" knowledge, Lawrence and Shapin 1998; on "situated knowledge", Haraway 1988, Longino 1990, Fausto-Sterling 1992. And for a critique of the epistemological basis of cartography, see Sieber and Haklay 2015.

[126] Marshall 2012.

[127] Murphy 2004.

[128] Wynne 1992, Wynne 1996.

showed that the farmers were capable of engaging in a critical discussion with experts about technical knowledge, and should not simply be considered ignorant believers.

6. Educational promises

6.1 Does citizen science increase scientific literacy?

Ideas concerning what citizens should know about science, and even if science should be part of a general education and have a place in culture along the humanities, have changed considerably over time.[129] In the twentieth century, it became increasingly clear that science should be taught in schools and included in any definition of "culture". At least since 1945, scientific education became an imperative for the training of a scientific and technical workforce that Western states needed to fulfill the promises of science and technology for national security, economic and social progress. This realignment of education with scientific thinking might explain the increased results in IQ test scores during the twentieth century, the so-called "Flynn effect". Political scientist James R. Flynn explained the change by suggesting that both culture and education across the developed world became more oriented toward scientific thinking, which is at the core of the IQ tests. This focus became increasingly true in the 1980 with the vision of a "knowledge economy" requiring even more "STEM workers".[130] The pressure for a successful science education resulted in numerous reports pointing to the limitations of formal school education, especially with regard to the experimental sciences. In the late twentieth century, as the notion of "scientific literacy" shifted from a narrow focus on "content knowledge" to include knowledge about the "nature of science" and the "nature of scientific inquiry" the limitations of school instruction, mainly based on classroom work, became even more apparent. International education achievement assessments, such as TIMSS and PISA, were giving a growing weight to the ability of learners to understand scientific research and the role of scientific knowledge in practical situations. In this context, the educational promises of citizen science, especially with regards to authentic scientific practice, were received enthusiastically. In the United States, the National Science Foundation became a strong supporter of citizen science, through its "Informal Science Education program".[131] As

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[129] DeBoer 1991.

[130] Kosmin et al. 2008.

[131] Strasser et al. 2018.

the citizen science advocate Rick Bonney put it in 2016, “Citizen science was the magic bullet the NSF was looking for”.[132]

Researchers have evaluated the learning outcomes of a number of citizen science projects. In a review of these evaluations, a team headed by Rick Bonney found that “data collection” projects such as eBird achieved “measurable gains in knowledge about science content or process” for participants, but no “noticeable changes in attitudes or behaviors” towards science (in part because attitudes were highly positive to start with). On the other hand, “data processing” projects such as Foldit did not result in a measurable increase in public understanding of science among participants. A study of “volunteer computing” projects, such as SETI@home, found that even if the projects did not require any kind of scientific engagement by the participants, they increased their scientific knowledge and general literacy (because participants became curious about the scientific topic and investigated it online).[133] Unsurprisingly, “curriculum-based” projects such as the GLOBE projects, where school students investigate their local environment, had the greatest impact on learning about scientific content and process, and on developing investigative skills and abilities to use scientific arguments in real world situations. Finally, the impact of grassroots community projects on learning had not yet been sufficiently evaluated to reach any conclusion. Thus the question of the educational outcomes of citizen science cannot be answered in general, but still requires to be examined on a case-by-case basis. Furthermore, only further studies will be able to show if citizen science actually does better (or is more effective) than formal science education and more traditional modes of informal education, such as museum visits, in increasing scientific literacy. It will also remain to be clarified what are the trade-offs between the scientific, educational, and democratic goals of citizen science.

A different way to think about the educational benefits of citizen science is to turn the relationship on its head. In many ways, citizen science is the result of the significant societal investment in scientific education, which has increased the educational level of the general population to unprecedented levels. As we will see (*Section* 7.2), the highly educated members of society are over-represented in citizen science projects, and therefore the scientific outcome of citizen science can be understood as a social return on investment in education. In this

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[132] Bonney et al. 2016.

[133] Kloetzer, Schneider and Da Costa 2017.

framing, the role of citizen science is not to increase scientific literacy, but to capitalize on the increased literacy that took place across society.

6.2 Does citizen science change attitudes towards science?

As noted above in the discussion about the crisis of expertise and the evidence of increasing scientific literacy, the expectation by some funders that attitude changes should be the main outcome of citizen science activities is somewhat naive, and does not take into account the background of participants, their knowledge, and their interest (let alone a critical view of the existence of a "crisis of trust"). Therefore, when looking at the impact of citizen science on attitudes towards science, it is necessary to think of both the participants and the scientists who are running these projects. While there is some evidence for changes in participants' attitude towards the environment through participation in citizen science,[134] as well as towards science,[135] these changes are usually modest. Research into the learning outcomes of citizen science have demonstrated that a too narrow approach to the question is likely to fail noticing significant personal development that occur in these projects, for example in learning about the project's technical aspects, engaging in a social activity, or increasing specific scientific understanding in the broader domain of the project.[136]

An equally important, but far less often noticed, aspect is the fact that involvement in citizen science has been shown to change *scientists*' attitude towards the public and their level of knowledge.[137] In a way, the importance of citizen science might reside even more in the changes in attitude of scientists towards their wider societal engagement and obligation, as well as in scientists gaining a more realistic understanding of the public, than in the changes in attitudes of already enthusiastic participants.

Within the diverse citizen science landscape, especially in the do-it-yourself movement, some voices have been critical of academic and corporate science. They have challenged some aspects of the scientific enterprise, for example with regards to intellectual property rights, conflicts of interests resulting from corporate funding, or simply the fact that cutting edge laboratory research can only take place in expensive and sophisticated laboratories away from

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[134] The Conservation Volunteers 2014.

[135] Price and Lee 2013.

[136] Jennett et al. 2016.

[137] Shirk 2014. However, for some of the difficulties, see Golumbic et al. 2017.

the public view and reach. But far from discouraging the public from engaging with scientific research, these promoters of do-it-yourself have opened the possibility for amateurs to re-engage with sciences by creating cheap scientific instruments and starting laboratories in alternative locations, from apartment kitchens to community hacker spaces. Even if a majority of participants in such projects often hold advanced degrees in science and already have significant experience in professional research laboratories it offers them opportunities to practice science outside of their main professional occupation.[138]

Through the personal ties of some participants, DIYbio groups often maintain strong connections with universities and other research institution. A number of institutions, such as the MIT, have actively supported the creation of independent biohacker laboratories, as a way to recruit talented researchers and encourage the emergence of innovative technologies. The vast majority of the participants in DIYbio activities are strong believers in the potential of (bio)technology and see it as part of their mission to promote and increase its use. In doing so, the DIYbio community has put great efforts in being exceptionally responsible and transparent with regard to laboratory safety norms.[139] It has also shown great enthusiasm for finding technological solutions to societal problems, however sometimes with limited consideration for the precautionary principle towards potential social and environmental harms. To summarize, the impact of citizen science on attitudes towards science, depends on who's attitudes precisely we focus on. But in all cases, the moderate criticisms of institutional science that is sometimes voiced by citizen science groups are largely offset by their enthusiastic discourse in support of the scientific enterprise.

7. Democratic promises

7.1 Does citizen science contribute to the democratization of science?

From distributed computing to crowdsourcing and to do-it-yourself science, almost all kinds of citizen science initiatives claim that they contribute to the "democratization of science". What exactly is meant by "democratization", however, is often unclear.[140] In a trivial sense, the meaning of "democratization" relates to the process of making the socio-demographic characteristics of the people involved in a given activity resemble more closely that of the

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[138] Seyfried, Pei and Schmidt 2014.

[139] Kuiken 2016.

[140] Chari et al. 2017.

general population. By contrast, professional scientists are not representative of the general population in terms of class, gender, age, and, obviously, education. Citizen science could contribute to making science more "democratic" in that sense by including participants that are (more) representative of the general population than the scientific community. This claim can thus be empirically tested by comparing the socio-demographics of the participants in citizen science projects to those of a given reference population (see *Section* 7.2). The political ideal behind this understanding of "democratic" is direct democracy, where all citizens (and only citizens) are called to decide about specific issues.

A second meaning of "democratization" is based on the tradition of representative democracy, i.e. a system that will produce decisions "for the people" by representative "of the people", and not necessary "by the people". In this sense, "democratizing" science means making science better serve the public interest, as the radical science movement of the 1960s (and beyond) hoped to achieve and as the "participatory turn" in science policy has emphasized since the 1980s. A democratic science in the first sense (where research is carried out by people who are demographically representative of the general population) is not necessarily democratic in the second sense (in the public interest); for example if participants have little agency in determining research goals. And a science can be democratic in the second sense, even if an unrepresentative elite carries out research, as long as the research goals are aligned with the public interest. Promoters of citizen science and the media alike often conflate both meanings making the assumption that democratic in the first sense will lead to democratic in the second sense: a science "by the people" would necessarily be "for the people".

In the large spectrum of citizen science projects, it is unclear whether there is a common agreement over what constitutes the "public interest". From environmental justice to user-friendly technologies and from biodiversity conservation to astronomical knowledge, citizen science projects aim to achieve very different goals in the name of the public interest. Behind empty slogans such as "making the world a better place" lies a great diversity of visions as to what that might mean practically and what the role of science in that process might be. But there is widespread agreement on one crucial point: science will be essential in achieving these transformative visions. Even the minority voices expressing some form of criticism about the role of institutional science in current democracies aim to reform, improve, or supplement institutional science with citizen science, not reduce the place of science or technology in society. The more radical voices, which challenge altogether the scientific worldview, especially vocal in the 1960s and 1970s, have become almost inaudible today. When this long tradition of "techno-critique" exceptionally expresses itself, it targets citizen science as much as institutional science. In a piece published in the *Atlantic* entitled "Why I am not a maker", an American faculty at a college of engineering has criticized the cult of turning every citizen into a "maker" of products because "it's not all that clear that the world needs more stuff" and because the citizen science maker movement "mostly re-inscribes familiar [corporate] values, in slightly different form: that artifacts are important, and people are not". For the author, there are alternatives to an exclusive focus on "making" (and innovation), such as repair and care for technology.[141] In a less articulate expression of a similar argument, anonymous techno-critical activists set on fire a French maker space and science center in Grenoble in 2017 to protest its support to "technocracy".[142] Thus within a broader view of science and democracy, citizen science remains firmly on the side of science, not its enemy. A view of the demographics of citizen scientists gives some indications as to why that might be the case.

7.2 Who are the citizen scientists?

If we examine the evidence on educational attainment of the European population in working age (25-55), current statistical information states that by 2015, about 27% achieved tertiary education, which is either college, university or equivalent (i.e. studies beyond high school). Thus, 73% of people had education below that level. There is variability between countries—for example, in the UK almost 40% of the population has tertiary education, 30% in France, 23.8% in Germany, and only 15% in Romania.[143] UNESCO statistics show that participation in tertiary education in developed countries increased from 35.9 million people in 1999 to 46.8 million in 2014, and participation at doctoral level increased from about 985,000 to about 1,343,000 people over the same period, remaining steady at about 2.8% of students.[144] Based on these statistics, if participation in citizen science was spread evenly across the population, about 30% of participants would be expected to have tertiary education, and about 1-2% to have a doctoral degree. Yet, the evidence is that people with higher education are overrepresented in citizen science. In Galaxy Zoo, a project in which participants classify galaxies and help astronomers to understand the structure of the universe, 65% of participants

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[141] Chachra 2015.

[142] Haegel 2017.

[143] Eurostat 2017.

[144] UNESCO 2016.

had tertiary education and 10% had doctoral level degrees.[145] In Foldit, 70% of participants had tertiary education, while in the volunteer computing project Folding@home, 56% had tertiary education. In OpenStreetMap, which aims to create a free, editable digital map of the world, 78% of participants hold tertiary education, with 8% holding doctoral level degrees.[146] Finally, Transcribe Bentham, a digital humanities project in which volunteers transcribe the writing of nineteenth-Century English philosopher Jeremy Bentham, 97% of participants have tertiary education and 24% hold doctoral level degrees.[147] Since many of the participants already have a high degree of education, the issue of increasing scientific literacy is not necessarily central (*Section* 8), but at the same time, these participants are capable, and are interested in learning about new domains of knowledge or more about areas of knowledge that they have not explored during their formal education.

In terms of gender, projects vary. While the OpenStreetMap survey was showing 97% male and IBM World Community Grid 90% male participants,[148] Transcribe Bentham, which is difficult technically, shows a majority of female participants—this was also true for a study of turtle nests in Florida.[149] So while many projects do show a gender bias, a simple explanation about technology use is not sufficient.

Beyond education and gender, projects also vary in the socio-economic background of participants, their spatial and temporal distribution. Upper-middle class people are over-represented. Thus, if citizen science is to be used to increase wider societal engagement with science, a special effort must be dedicated to the engagement of people with lesser education attainment.

7.3 Why do citizens participate?

Concerns over the motivations of participants to take part in citizen science projects have been a persistent feature of research into citizen science, so much so, that even the restricted pool of papers in the ISI Web of Science identifies 103 papers in the combination citizen science and "motivation". The research has overwhelmingly demonstrated that interest in science and the

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[145] Raddick et al. 2010, Curtis 2015.

[146] Budhathoki and Haythornthwaite 2013.

[147] Causer, Tonra and Wallace 2012.

[148] World Community Grid 2013.

[149] Bradford and Israel 2004.

willingness to contribute to knowledge are significant factors in motivating participants to engage and maintain their engagement with the field.

A recent review in the area of ecology and biodiversity shows that motivations can be intrinsic (personal satisfaction, having a reason to go out and explore the environment) and extrinsic (social activity, career opportunities).[150] Some of the models for motivations are overlapping with the wider volunteering and psychological studies of motivation, while project specific motivations can also be identified—from personal connection as a patient (or a sick family member) as a reason for getting involved in a medical citizen science project to interest in astronomy when joining Galaxy Zoo. Concern for the environment and biodiversity is also frequently mentioned in environmental projects.[151]

The analysis of motivations should also notice the difference between joining a project, carrying out the activity just once, and ongoing engagement over time, with different ways of carrying out projects leading to different patterns of engagement and longevity. Thus, a project that requires data collection at a specific time and a specific place, as common in weather observations, will have different characteristics from an opportunistic project that allows the participants to submit data whenever they wish to do so.

Of special importance is to think about the motivations not only of the participants but also of the scientists, funders, and other stakeholders who are involved in a given project. Citizen science projects usually have multiple goals and objectives—from education to production of highly cited and innovative academic papers. These multiple goals mean that consideration of the motivation of participants and stakeholders should be included in project design and execution, and careful alignment and discussion need to be included to ensure that the duty of care of project organizers towards the participants is taken into account. Since there is a risk of using participants' motivations as a way to manipulate them and extract more unpaid work from them, a strong commitment to mutual benefits in citizen science projects is necessary.

7.4 Does citizen science empower citizens?

Like democratization, the term "empowerment" has been used with multiple meanings over the years (with celebrity Kim Kardashian adding her own interpretation). As noted in previous

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[150] Geoghegan et al. 2016

[151] Bradford and Israel 2004.

sections, the concept revolves around the idea of handing power from a group of powerful social actors to an actor, or a group, with much less power. This is usually in a way that allows autonomy and self-determination over issues that they are directly concerned with. Evidence for empowerment in citizen science abound—from the individual case of rare disease sufferers who come together to carry out an experiment about the efficacy of a treatment to the group action of AIDS patients in the 1980s, and to communities who are using citizen science within environmental justice struggles.

However, to date, no explicit theory and framework for empowerment have emerged. Empowerment in citizen science can take many forms, and therefore a careful and nuanced analysis is required. For example, in volunteer computing, the act of joining a project that addresses cancer, when the participant has a personal experience of the disease, can make the person empowered in the sense that they are contributing something to the issue. There is evidence that even in game-like systems such as Foldit and EyeWire participants are benefiting from this sense of empowerment.[152] At the other end of the spectrum, when indigenous forest communities in the Congo-basin are given an opportunity to map their resources and secure them from destruction by logging companies, the empowerment is more pronounced in its political and physical outcomes.[153] In between, there is the personal empowerment of people with physical or mental health issues who, through participation, gain a sense of contributing to society.[154]

Yet, the issue of empowerment brings to the fore the overwhelming power that science is wielding in current societal processes. For example, the need for community-led citizen science in environmental justice issues is emerging from the framing of environmental policy choice through scientific lenses as usually an exclusive form of valid knowledge. While other areas of decision making provide the space for perceptions, values, religion, and personal histories (e.g. education), environmental decision making excludes most of these and therefore the route to empowerment must go through the process of generating and securing scientific information.[155] This is true for other cases of empowerment through citizen science—for example, the actions of AIDS patients in the 1980s were not about the act of generating the scientific knowledge

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[152] Jennett et al. 2016.

[153] Stevens et al. 2014.

[154] Koss and Kingsley 2010.

[155] Haklay 2017.

itself, but about the way medical science set their procedures for defining what knowledge counts.[156] Thus, part of the empowerment that citizen science brings is about the politics of the scientific enterprise itself, and the concepts of knowledge creation.

8. Citizen science organizations and relation to policy

8.1 Citizen science organizations

Since 2010, the distributed network of activities carried out under the banner of citizen science has started to become institutionalized through the creation of formal organizations, such as associations or advisory groups for national and international governmental agencies, but also more fluid "communities of practice" bound through mailing lists and online platforms across various geographical scales.

The US-based (global) Citizen Science Association (CSA), the European Citizen Science Association (ECSA), and the Australian Citizen Science Association (ACSA), founded in 2012, 2013, and 2014 respectively, were established after years of informal interactions between their future members, born out of the recognition that an official organizational structure could help to consolidate and develop the field. These organizations provide a channel for sharing knowledge and tools, and represent the interface between the membership and external stakeholders such as policy makers and academia. The use of English language platforms has helped the CSA and ECSA to draw in a global membership, with representatives from across 80 and 27 countries respectively. As they currently operate, these organizations are separate legal entities within larger institutions, granting them independence on issues of governance and access to public funding opportunities. In recent years, capacity building through ECSA and the translation of its *Ten Principles of Citizen Science* into 24 languages has started to filter into the development of national platforms and support infrastructures. New membership associations have also started to emerge beyond Western geographies, in China and Africa especially. These new networks are in early and fragile stages of development, sometimes consisting of only a handful of individuals, and yet they have already taken steps to reach out to their more established counterparts.[157] This may help to bring new cultural perspectives on community-based research and relations with academia, eventually developing alternative structural models to the existing Western approaches. In December 2017,

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[156] Epstein 1996.

[157] Göbel et al. 2017.

representatives of CSA, ECSA and the ACSA launched the Global Partnership for Citizen Science, aiming to provide an interface for citizen science coordination at the global level. The governance principles of this “network of networks” are still undecided, but will need to consider issues such as fair access and representation. As the size and influence of international citizen science associations grow and they become increasingly integrated into the political arena, their more professionalized nature may create tensions with the grassroots principles upheld by some of their membership.[158]

Some national learned societies, such as the Swiss Academy of Sciences (SCNAT) in Switzerland, have played a vital role in supporting national citizen science networks. Cross-border organizations such as the League of Research Universities (LERU) and the Global Young Academy (GYA) are also helping to raise awareness of citizen science amongst the international research community and with policy audiences. Both the Organisation for Economic Co-operation and Development (OECD) and the World Economic Forum (WEF) have highlighted the potential of citizen science for research, innovation, education, or democracy. In its 2016 Global Risks Report, the WEF featured citizen science as one of three innovative approaches to “encourage inclusive and stable societies”.[159]

Citizen science has been particularly attractive for environmental bodies and advisory groups. At the supranational level, the United Nations Environmental Programme (UNEP), after supporting the Global Mosquito Alert project in 2015, has introduced a citizen science portal on its online data repository UNEP Live. The importance of citizen contributions to helping nations realize their commitment to the Convention on Biological Diversity (CBD) has been recognized by both the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) and the Global Biodiversity Information Facility (GBIF). Indeed, it is difficult to imagine how the CBD can be upheld without involving volunteers for data gathering and interpretation due to paucity of professionals and resources in this sphere.[160] These organizations and others, including the European Network of Environmental Protection Agencies, have emphasized a role for citizen science in addressing global challenges and achieving the Sustainable Development Goals (SDGs). The Stockholm Environment Institute

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[158] Haklay 2015, Göbel et al. 2017.

[159] World Economic Forum 2016.

[160] Chandler et al. 2016.

has argued that community-based science could make a three-fold contribution to sustainable development. Firstly, through defining sub-national targets based on knowledge of local context, secondly, through monitoring and contributing data to identify gaps and increase the accountability of authorities and finally, through co-creation and implementation of projects based on local priorities to help seed relevant and lasting behavioral change.[161]

8.2 International, national, and local policy initiatives

Policy initiatives with implications for citizen science straddle the two principal dimensions of science policy: “policy for science” (i.e. policies that shape research funding and innovation within traditional institutions and industry) and “science for policy” (i.e. the formalized practice of including scientific data, evidence and advice for policy making). Considerations related to whether citizen science, both in its narrower and broader sense, requires the formal integration into “policy for science” (or research policy) are quite separate to whether the knowledge generated by citizen science practices could serve a wider societal need in terms of informing the policy process (citizen “science for policy”).

Citizen participation can provide input at various stages of the policy cycle—from research agenda setting and forecasting to implementation and monitoring practices.[162] But the relationship between citizen science organizations and policy makers requires considerable efforts from all sides to establish and maintain in the longer term. Alternatives such as input from professional scientists in the case of environmental monitoring may be the more cost-effective and ethically appropriate choice.[163] Only clarity about the intended aims of the required input and a careful assessments of the resources institutions are willing to commit, on a case-by-case basis, can allow the process to function effectively.[164]

8.3 European Union policies related to citizen science

The inclusion of citizen science in policy initiatives has increasingly been touted as a driver of positive behavioral change by the European Commission, particularly in relation to

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[161] Pateman and West 2017.

[162] NACEPT 2016, Schade et al. 2017.

[163] Pocock et al. 2013.

[164] Nabatchi and Amsler 2014, Chapman and Hodges 2017.

environmental stewardship, participatory democracy, public health, and innovation initiatives.[165]

Between 2017 and early 2018, Directorate General for Environment (DG ENV) issued no less than three Action Plans calling for increasing opportunities for citizens to become involved in environmental management: “Nature, People and the Economy”; “Streamlining of Environmental Reporting”; and “Compliance Assurance”. The latter two documents explicitly call for citizen science to be used as a complement to official monitoring procedures. These Action Plans are intended to boost implementation of Environmental Directives by Member States through addressing resource efficiency and public accountability concerns for the responsible policy bodies. Other environmental policy areas where citizen contributions are being currently considered include Air Quality, Invasive Alien Species, and Biodiversity Monitoring.

Beyond environmental policy, the Directorate General for Research and Innovation (RTD) funded an early wave of cross-border citizen science projects through the Commission’s Funding Framework Programme 7 (FP7) between 2007 and 2013. The “Science and Society” theme was first introduced as a standalone program within the Commission’s FP6 framework (2002-2006) as a result of earlier scoping activities, which had indicated a disconnect between the R&I activities supported by the European Union and its citizens.[166] The scheme saw an increase in budget under FP7 (2007-2013), but remained a modest part of the total budget (from 0.5% to 0.66%). It also saw an adjustment in name from “Science *and* Society” to “Science *in* Society”, and to “Science *with* and *for* Society” in Horizon2020 (2014-2020), with funding remaining at ~0.6% of the total. The changing denominations and rationales for the program reflect the evolution of the EU’s conceptions of public engagement which increasingly involve citizens in the production of scientific knowledge, understood as “innovation”, and not only in deliberations about science policy. Indeed, such top-down “terminological shifts” in science policy are rarely value-free. The use of Responsible Research and Innovation (RRI) terminology by the Commission places a priority on “socio-economic benefits” and societal needs as the crosscutting frame for the EU science policy agenda during Horizon2020.[167]

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[165] McKinley et al. 2017, European Group On Ethics In Science And New Technologies 2015.

[166] European Commission 2002.

[167] Zwart, Landeweerd and van Rooij 2014.

Although RRI was developed specifically as an answer to a perceived crisis of innovation, it allowed citizen science projects to be justified within almost any funding call issued by DG RTD, even outside of the "Science with and for Society" work program, by emphasizing the links of the field with public engagement, science education, and societal innovation.

Several benchmark citizen science initiatives were launched, starting with the Commission's Funding Framework Programme 7 (FP7), including Citizen Observatories, the SOCIENTIZE project, and the "Technology Enhanced Creative Learning in the field of Citizen Cyberscience" with the Swiss Citizen Cyberlab as a key partner. The Citizen Science White Paper (2014), produced by stakeholders involved in SOCIENTIZE, set out a widely circulated vision for what was needed to enable sustainability for citizen science in Europe. Since 2014, several pan-European projects ranging in focus from biological and environmental sciences to cultural engagement have received funding through Horizon2020, such as Doing It Together Science, which is organizing events "across Europe focusing on the active involvement of citizens in Citizen Science".[168]

Citizen science has also benefited from a platform within the European Commission's Open Science Policy Agenda championed by Commissioner Carlos Moedas as part of an action towards "Fostering and creating incentives for Open Science". In this framing, the role of citizen science is defined as falling somewhere between "the supply and demand side of open science", making it more difficult to analyze than other measures such as Open Access and Open Research Data (RAND Open Science Monitor). To better understand this scope, the European Union's in-house science service, the Joint Research Centre (JRC), has been granted a mandate to research the links between citizen science and "active citizenship".[169] However, the main vision behind the EU's support for citizen science was not about citizenship, but about supporting innovation and the "knowledge economy". The Joint Research Centre work, as well as the EU's support for the further study of the field by social scientists (e.g. through the "COST Action Citizen Science to promote creativity, scientific literacy, and innovation throughout Europe"), aims to offer an assessment of motivations, impact, and implications of further integrating citizen science into the policy cycle. It remains to be seen, however, whether the

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168 "Doing it together science", http://www.togetherscience.eu/ (accessed, 22.3.2018).

169 Schade et al. 2017.

inclusion of citizen science in policy agendas signals a longer-term culture change in research that will outlast the tenure of prominent high-level champions.

8.4 National strategies and research & innovation policy

A prominent example of policy support for citizen science at the national scale is the federal Crowdsourcing & Citizen Science Act introduced in the United States House of Representatives in 2016 and passed into law as part of the American Innovation and Competitiveness Act in January 2017. The Act encourages Federal Agencies to use crowdsourcing and citizen science because of its numerous benefits: “accelerating scientific research, increasing cost effectiveness to maximize the return on taxpayer dollars, addressing societal needs, providing hands-on learning in STEM, and connecting members of the public directly to Federal science agency missions and to each other”. The Act concluded that crowdsourcing and citizen science would yield “numerous benefits to the Federal Government and citizens who participate in such projects”. To support citizen science, the US Government General Services Administration launched a federal website, CitizenScience.gov, bringing together all federally funded citizen science projects and promoting its Federal Toolkit for citizen science. After less than two years, the US federal “community of practice” had grown to include over 300 members across 35 governmental agencies. Crowdsourcing and citizen science have been referenced in additional federal legislation such as the Environmental Justice Act proposed in 2017.[170] The Wilson Centre, a policy think tank supported by the government, who worked out important regulatory issues affecting citizen science such as legal issues and intellectual property rights, facilitated these legislative changes and policy resources.[171]

On a more modest scale so far, the coordination of European citizen science networks across Germany, Austria, Switzerland and Spain have resulted in active online national platforms. In Germany, these efforts were born out of the two-year capacity-building program *GEWISS*, supported by the German Federal Ministry of Education and Research, which resulted in 2016 in a *Green Paper* drawing on the input of over 700 participants from 350 organizations and outlining a “Citizen Science Strategy 2020 for Germany”.[172] In 2017, the Ministry of Education and Research followed-up on a recommendation of the *Green Paper* and created a dedicated

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[170] H.R.4114 - Environmental Justice Act of 2017.

[171] Gellman 2015, Scassa and Haewon 2015.

[172] Bonn et al. 2016.

funding call *Mitmachen und Forschen* (Collaborate and Research). In the first found, higher education and research institutions led 11 out of 13 projects funded by this scheme and an NGO or an association coordinated two.

In France, the *Fondation sciences citoyennes*, created in 2002, has attempted to reinforce the research and expertise capacity of civil society. It has also worked to re-politicize science in order to open it to democratic debate and has remained critical of institutional research initiatives which do not give significant power to the participants.[173] For example, the *Muséum national d'histoire naturelle*, another early advocate of citizen science, has called for extending participation in scientific research but only under the direction of professional scientists.[174] Citizen science gained additional visibility in France, after the publication of the report *Les Sciences participatives en France* in 2016, commissioned by the Minister of Higher Education & Research and carried out by the Institut National de la Recherche Agronomique (INRA).[175] One year after its publication, the Ministry organized the signing of a national Charter on participatory science and research, supported by 30 organizations across research and civil society. A number of these have joined forces in the association "Pour une alliance sciences sociétés (ALLISS)" to influence policy with regard to citizen science, along the lines of their white paper, *Prendre au sérieux la société de la connaissance* published in March 2017.[176]

The United Kingdom hosts a strong citizen science community, as almost 18% of the ECSA membership, in 2018, were based in the UK. Despite this strong representation at the European level, the presence of several high-profile projects such as Big Garden Birdwatch, Open Air Laboratories, The Zooniverse, and a healthy network of makerspaces and fablabs, there has been a notable absence of a coordinated citizen science strategy on a national level. However, in 2017, the National Environmental Research Council provided funding for a pilot project to bring together the environmental citizen science community to establish a community of practice with a focus on "building capacity through training in citizen science and developing

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[173] "Présentation de Sciences Citoyennes", April 13, 2003. Available at Internet Archive Wayback Machine: https://sciencescitoyennes.org (accessed, 20.3.2018).

[174] Bœuf, Allain and Bouvier 2012.

[175] Houllier 2016.

[176] Akrich et al. 2017, Aguiton 2014, ch. 4.

local communities of practice to prepare for a nationwide programme of public engagement with environmental sciences”.[177]

In Switzerland, the Foundation *Science et Cité* created the Swiss Citizen Science Network in 2016 and the online platform *Schweiz forscht* in 2017 to bring more visibility to citizen science projects based in Switzerland (like the US-based SciStarter platform containing over 1,000 projects).[178] On this platform, citizen science providers, the interested public, school teachers and the media, can easily search citizen science projects by themes (climate, fauna, health, etc.) and find a synthetic description of the project. The Foundation *Science et Cité* has also organized a wide range of workshops and conferences on citizen science to help build a community around citizen science and connect potential citizen science participants, scientists, and funders. They have taken the lead in organizing the Second International Conference of the European Citizen Science Association (Geneva, 2018).

Other European countries have developed similar initiatives. Italy held its first national Citizen Science conference in November 2017 sponsored by the National Academy of Sciences and the Italian National Research Council (CNR); and in early 2018, a three-year project to develop a national platform was launched in Sweden through the government’s *Kunskap i samverkan* (Knowledge in collaboration) strategy. Thus, national citizen science initiatives have typically relied on collaborative efforts between civil society groups and institutions (academic institutions and museums) but also on political support from high-level champions willing to include citizen science in research and innovation agendas.

The growing governmental support for citizen science has been driven by a number of factors. First, certain types of citizen science, such as do-it-yourself (DIY) and “maker” projects, are understood as a way to foster innovation and entrepreneurship. Second, citizen science is understood as a way for individual countries to fulfill their international obligations for environmental monitoring. For example, data on changes to bird populations tracked by amateur ornithologists has helped countries across Europe satisfy reporting obligations for the EU Birds Directive, and more generally citizen science data has crucially contributed to fulfilling national obligations towards the Convention on Biological Diversity (CBD). Third,

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177 “Projects funded to engage public with issues of environmental science”, http://www.nerc.ac.uk/latest/news/nerc/funded-pe-projects/ (accessed, 22.3.2018).

178 “Schweiz Forscht”, http://www.schweiz-forscht.ch/de/, “SciStarter”, https://scistarter.com/ (accessed, 22.3.2018).

citizen science is supported in the name of science communication and public engagement with science, and as a way to address public distrust in science, which could undermine science research policy (in Switzerland, the 1998 referendum against genetic engineering acted as a warning call).

8.5 Cities, districts and regions

Some citizen science projects rely on funding and coordination support from administrations at city, local and regional levels. In recent years, the increased integration of new information and communication technologies into public service delivery at the municipal scale has given rise to the concept of the "Smart City". Beyond the emphasis on technological innovation that risks placing automation rather than people at the heart of urban living,[179] the Smart Cities approaches have been evolving to recognize the potential for citizens to become key collaborators in data gathering, analysis, and innovation for a networked urban living.[180] Examples range from environmental "citizen sensing" projects such as Making Sense in Amsterdam to the co-creation of innovative solutions for local issues seen in the "Bristol Approach", which consists of a "a new way of working that puts communities and their needs at the heart of innovation".[181] Other opportunities for community-based science can arise through participatory budgets and similar city-level schemes. In 2014, the Mayor of Paris dedicated 5% of the city's investment to the "*Budget Participatif*" until 2020 in order to support grassroots projects dedicated to improving the quality of life in the city. A growing number of projects, selected by citizens themselves, have brought together professional scientists and citizens in finding solutions to urban problems.[182] Similarly, Crowdfund London asks citizens to pledge support for the community projects they want to see transform the city and the most popular projects receive match funding from the Mayor's Office.[183]

As well as funding support, local authorities, city councils, and other statutory bodies have provided entry points for citizen science groups interested in linking their projects to policy impact. The pan-European WeSenseIt project demonstrated the potential of co-created

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[179] Greenfield 2017.

[180] Saunders and Baeck 2015.

[181] "A new approach to citizen science", http://making-sense.eu/; "The Bristol Approach", kwmc.org.uk/projects/bristolapproach/ (accessed, 22.3.2018).

[182] "Budget Participatif", https://budgetparticipatif.paris.fr/bp/ (accessed, 22.3.2018).

[183] "Crowdfund London", https://www.spacehive.com/movement/mayoroflondon (accessed, 20.3.2018).

solutions between citizens and district authorities for flash flood management across locations in Italy, Netherlands and the UK. This project has secured ongoing support from the participating local authorities, even leading to a new policy, Digital Defland, from the regional water authority in the Netherlands.[184] In Ireland, the Local Agenda 21 Environmental Partnership Fund (LA21 EPF) supports projects involving collaboration between civil society groups and local authorities to address varied environmental issues including pollution, waste and sustainable development.[185] There is evidence to suggest that when local environmental management involves local communities, it is more efficient and immediately responsive to needs.[186] The empowerment achieved through engagement with local governance structures can be a key motivating factor for citizen participation, yet such collaborative schemes can only succeed when there are structural and procedural commitments from institutions to confer real decision-making power to citizen groups.[187] More research is needed on the effects of contextual settings, motivations of actors and the links between processes and outcomes of participatory governance, as evidence is still scarce on the most equitable and successful designs.[188]

8.6 Other sources of funding

Foundations, charities and trusts have also supported citizen science through grants that are less entangled with policy objectives and R&D strategies offering grassroots communities more flexibility. The National Lottery Fund in the UK, which funds both hyper-local and national projects is one such example. Its Big Local Community Grants managed by local residents have supported citizen science air quality monitoring schemes in Eastbourne, while the nationwide citizen science project Open Air Laboratories (OPAL) received long-term support between 2007 and 2017, attracting over one million participants by 2018.[189] The internationally focused Mozilla and Shuttleworth Foundations have also helped citizen science groups to build capacity through fellowship grants awarded to community facilitators.

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184 http://www.wesenseit.com/.

185 “Local Agenda 21 Partnership Fund”, https://www.dccae.gov.ie/en-ie/environment/topics/environmental-protection-and-awareness/local-agenda-21-partnership-fund/Pages/default.aspx (accessed, 20.3.2018)

186 Danielsen, Burgess and Balmford 2005.

187 Parrado et al. 2013, O’Hare 2010, Devaney, Shafique and Grinsted 2017.

188 Nabatchi and Amsler 2014, Devaney, Shafique and Grinsted 2017.

189 Andydharma 2017, www.opalexplorenature.org.

Online crowdfunding platforms, such as experiment.com and the more specialized digventures.com, have provided alternative sources of funding for citizen science projects unable to access traditional research funding. In Switzerland, the crowdfunding platform wemakeit.com, founded in 2012, has also supported participatory research. Benefits of this approach include developing a supportive online audience for the work and the ability to raise funds quickly, particularly for projects that make effective use of social media to generate attention. Crowdfunding is most successful for one-off projects on shorter timescales, while groups seeking longer-term support can struggle to retain the crowd interest beyond discrete goal-directed campaigns.[190]

9. Conclusions and policy options

Citizen science, and more generally participatory approaches to the production of scientific knowledge, have gained a tremendous momentum in recent years. Emerging from grassroots organizations and from established scientific institutions, participatory initiatives have flourished across the Western World and increasingly in China and the Global South. The scientific, educational, and democratic promises of citizen science have made this approach particularly attractive to all levels of government, from the local to the transnational levels as well as to civic organizations as a way to empower citizens on issues of direct concern to them (health, environment, etc.).

The future of citizen science is difficult to predict and will depend, among other factors, on the kind and extent of public support it will receive. Maximizing the scientific, educational, and democratic promises of citizen science at the same time might not be possible as these opportunities involve significant tradeoffs. A too narrow focus on the scientific outcomes, for example, could lead to exploitative practices and miss out on the democratizing and educational possibilities of such projects. Given these tradeoffs, the most desirable policy options will very much depend on which ones of the opportunities of citizen science—scientific, educational, democratic—will be emphasized and which stakeholder—higher education institutions, science funding agencies, policy-makers, grassroots organizations, etc.—will determine these priorities.

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190 Bone and Baeck 2016.

(1) General policy options

A number of useful policy recommendations have been proposed by the LERU in its 2016 report *Citizen Science at Universities: Trends, Guidelines and Recommendations*.[191]Among these, we would like to highlight the following general recommendations:

1.1) *Raise awareness about citizen science*. Recognize and raise awareness about the fact that citizen science is a "valid and rapidly evolving set of research methods", that brings along a unique potential for societal and educational benefits. In particular, "raise awareness amongst researchers of criteria for successful citizen science, including community management, pedagogical explanations, open science standards and social diversity by appropriate measures such as courses in citizen science" (62).

1.2) *Create a one-point entry for citizens in research and science finding organizations.* Create in research and funding organizations a "single and visible point of contact for citizen science… to advise and support scientists and ensure liaison with national and regional citizen science associations." (62) However, this contact person should not be part of the communication team (which would reinforce the view that citizen science is mainly about outreach) but in a directorate position, ideally attached to research with expertise in guiding and managing such projects in a mutually beneficial way. Linkage to organizations that can share best practice such as the European Citizen Science Association is also recommended as part of this function (62).

Additional policy options for science funding agencies, higher research organizations, and policy makers, could contribute to realize the full potential of citizen science for science and society.

(2) Policy options for science funding agencies

2.1) *Include citizen science in the evaluation of social relevance and impact of research grant applications*. Almost all science funding agencies include in their grant application guidelines a section for social relevance and impact. But usually, this dimension is given little attention by applicants and the evaluation of social relevance and impact plays hardly any role in the

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[191] Grey, Wyler and Fröhlich 2016.

actual selection process. Citizen science projects could actually provide an excellent way for researchers to increase the social relevance and impact of their research projects. Although this might not apply to all research projects, past examples of citizen science projects have covered a wide range of disciplines, from high energy physics to linguistics, demonstrating that almost any research project could involve citizens.

2.2) *Support citizen science as a potential tool for science communication*. The support for science communication and outreach too often relies on outdated models of the relationship between science and society. The overall goal of educating the public, irrespectively of the public's actual interests and needs, may actually reinforce the view of academia as an ivory tower and scientists as out-of-touch. Similarly, the attempts at creating a "public dialogue" around scientific issues too often turns into a transparent attempt at convincing the public to adhere to scientists' views. Giving more support to participatory research projects and letting citizens have an actual voice in the research process, including the definition of the research agenda, could go a long way in creating the basis of mutual trust and understanding that is necessary for a truly democratic dialogue on scientific and technological issues. Existing funding schemes, such as the Swiss National Science Foundation's Agora program, could place a greater emphasis on supporting citizen science, rather than end-of-pipe science communication.

2.3) *Include a broad set of criteria in the evaluation of citizen science projects*. There is no unique metric by which to measure excellence of citizen science. In order to be able to support the most beneficial projects for science and society, the evaluation of citizen science projects should not be limited to standard measures of scientific quality, but include social relevance, local impact, and contribution to attaining society goals, such as sustainable development or environmental justice. Such evaluations cannot be conducted by academic scientists who are experts in a given field but will have to be more interdisciplinary and inclusive. If, as noted above, projects will consider their goals and tradeoffs carefully and explicitly, it will be possible to evaluate the project against the goals that its initiators have chosen, as well as more clearly identifying serendipitous outcomes that were not originally planned.

2.4) *Support citizens' (re)engagement with citizen science through "mini-grants"*. One major difficulty for citizens involved in community or individual research projects is that their capacity is limited by the fact that they are volunteer-based and self-funded, creating a major barrier to growth and sustainability. This barrier could be overcome through access to small amounts of funding (e.g. short-term fellowships or mini-grants to supplement part-time income) to buy time for community organizers, for building a prototype or developing a proof of concept that can then be used for further fundraising, or for training in the relevant field and acquiring the organizing skills (travel funds, peer-mentorship). The Open Knowledge Foundation and the Federal Ministry of Education and Research (BMBF), for example, provide a Prototype Fund offering small grants (under EURO 50,000 for six months) for citizens to "implement [their] idea from the first concept to a prototype". The Mozilla Fellowships for Science, the Knight Foundation, the Shuttleworth Foundation, and Public Laboratory similarly offer short-term funding (under one year) for research projects that contribute to specific societal outcomes (such as open science). A similar funding scheme could be established in Switzerland to foster scientific research performed by citizens working outside of traditional research institutions.

(3) Policy options for research and higher education institutions

3.1) *Take into account the economic situation of citizens and grassroots organizations*. The vast majority of citizen science projects involve collaboration between a research institution and either individuals or grassroots organizations. For such a collaboration to be equally beneficial, it is crucial to take into account the unequal resources of both partners. Most grassroots organizers or individual participants, unlike academic researchers, cannot rely on a fixed salary and their contribution in time and expertise to a collaborative research project, to running an educational workshop, or giving a talk, should thus be financially defrayed.

3.2) *Provide access to the scientific literature to citizens.* For citizens to be able to contribute to scientific knowledge outside of research institutions, they need to be able to access the latest scientific findings. Open access policies mandating institutional archiving (green route) will contribute significantly to making published knowledge accessible to people working outside of scientific institutions. But until open access becomes a standard feature, institutions could provide, on request, access to institutional subscriptions to periodicals, accessible through a VPN. Similarly, the vast majority of scientific conferences are only accessible to those who pay registration fees, preventing, practically, non-professionals from attending. At almost no cost, organizing institutions could provide free passes for non-professionals to attend the scientific program of conferences.

(4) Policy options for policy makers

4.1) *Involve citizens in environmental monitoring*. A number of governmental obligations, such as biodiversity or air quality monitoring, could benefit from a greater public participation. The involvement of citizens in these tasks would not only allow for a greater density of data collection, but also in the gathering of data in areas that matter most to citizens. Opening-up the research design and methodologies to citizens can also, as the examples of "Fenceline Monitoring" in the United States demonstrates, contribute to taking into account dimensions that have been overlooked in official surveys. Innovative and cheap technical solutions have also emerged from opening up these monitoring projects to a larger participation, as in the case of *SafeCast* for radioactivity monitoring. Such initiatives may empower citizens and strengthen civic life and democracy.[192]

4.2) *Support citizen science as a complement, not a replacement, for institutional science*. It is essential that the greater involvement of citizens in fulfilling governmental obligations does not replace the work carried out by professionals affiliated with research institutions. In the case of monitoring, for example, the continuity of the necessary expertise and the long-term data management and preservation will require a strong institutional basis. Support for citizen science should thus complement the work performed by traditional research organizations.

4.3) *Encourage school science education to engage with citizen science.* Currently, the main focus of science education is on content knowledge. However, in order for citizens to be able to engage critically in public debates involving science and technology, from climate change to GMOs, it is essential that they also acquire a basic understanding of the nature of scientific inquiry. Participation of school students in citizen science projects, from mapping biodiversity to building air quality detectors, can provide a much needed exposure to the principles of scientific research and promote learning about the possibilities, challenges, and limitations of scientific research.

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[192] Noveck 2017.

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