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Citizen Science:
Probing the Virtues and Contexts of Participatory Research

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Abstract

Citizen science is an increasingly popular activity, from bird counts to amateur water sample collection to air quality monitoring. Researchers and theorists in the field of science and technology studies (STS) have typically applauded these efforts because they make science more participatory, providing an example of the democratization of science, or, at least, more equitable engagement between experts and the lay public. However, a broader review of the literature on citizen science suggests that participation is but one of many virtues that practitioners and observers find in the practices of citizen science. This literature review makes two interventions. First, we discuss the dimensions of citizen science that do not easily fit in a typology or spectrum of participatory practices. We identify seven different virtues claimed of citizen science: increasing scientific data; increasing citizens' scientific literacy and awareness; building community capacity for environmental protection; building more equal relationship between scientists and citizens; filling knowledge gaps and challenging official accounts; driving policy change; and catching polluters. Second, we consider the social and political contexts that often create contradictory situations or dilemmas for citizen scientists. Going forward, a robust framework for the analysis of citizen science would not only address the ways scientific data is collected and put to a particular use, but also situate the project in relation to broader structural forces of scientization, neocolonialism, globalization, and neoliberalization.

Keywords

citizen science; citizenship; participation; social movements

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Introduction

Citizen science is a popular activity, from bird counts and watershed assessment to participatory pollution monitoring and mapping. In this review, we discuss heterogeneous perspectives on what citizen science means and why it should be pursued. Many studies applaud citizen science because it makes science more participatory, providing an example of more equitable engagement between experts and the lay public (Cavalier and Kennedy 2016). However, our review of the citizen science literature calls into question the central focus on fostering participation. We reach two main conclusions. First, participation in science is one of many possible virtues of citizen science, but robust debate about these virtues is sorely lacking. Second, social and political contexts often create contradictory situations for citizen scientists, but such dilemmas have not received sufficient attention in the large and growing body of literature on this topic.

In STS, researchers and theorists have generally interpreted the rise of citizen science as a sign of the democratization of science, since it enables people without professional credentials to produce scientific knowledge. The research focus on *participation* has sometimes led to critiques of citizen science projects that are not participatory enough; for example, if participants are not permitted to define the questions or analyze the data, or if their contributions are used for purposes not of their choosing (Goodwin 1998; Ellis and Waterton 2004; Lawrence 2006; Lakshinarayan 2007; Shirk et al. 2012; Haklay 2013; Irwin 2015; Cooper and Lewenstein 2016). There are calls for "extreme citizen science," which emphasizes "bottom-up," socially transformative projects with marginalized peoples (see, for example, the Extreme Citizen Science group at University College London).

Our own experiences as participant observers in citizen science projects have led us to question the focus on participation as the defining virtue of these new forms of knowledge-making. Kimura (2016) studied the case of radiation monitoring after the Fukushima nuclear disaster. Women—mostly mothers—initiated and carried out a highly sophisticated effort to analyze foods for radioactive contamination. Kinchy (2016) studied volunteer watershed monitoring in a region where natural gas development is changing the landscape. Both citizen science efforts could be described as highly participatory; in many cases they were initiated by activists, and monitoring locations and materials were often chosen based on local knowledge. But much more can be said about each of these citizen science cases and what participants believe they accomplish. Advocates of post-Fukushima radiation monitoring implicitly extol numerous virtues of citizen science: accumulate data on radiation, help people make safe choices, and reveal falsified or incomplete data. In the case of watershed monitoring, volunteers indicate that they are picking up the slack where their government lacks monitoring resources, preparing for future confrontations with the gas industry, and deterring illegal dumping by surveilling industry behavior. In each case, public or democratic participation in scientific knowledge-creation is only one virtue of the project.

Our observations resonate with the diversity of claims that practitioners and observers have made about the contributions of citizen science, discussed in this review. Studies have shed light on how citizen scientists raise environmental consciousness, shift media and policy discourses, and drive policy changes, among other virtues. We also note, by looking at other cases of citizen science and environmental activism, that deep and active participation in scientific knowledge making does not necessarily enable people to challenge powerful institutions (such as the nuclear industry) or achieve desired outcomes (such as preventing pollution of a valued watershed). Sometimes shallow participation, such as simply using data that has already been produced by professional researchers, is sufficient to enable communities to effectively advocate for environmental protection, public health, and social justice (Allen 2004; Morello-Frosch, Pastor, and Sadd 2012).

For these reasons, we review the literature on citizen science with the aim of uncovering the dimensions of citizen science that do not easily fit in a typology or spectrum of participatory practices. Our review decenters participation as the central feature of citizen science, placing it among several other claimed or assumed virtues. We will examine how citizen science is practiced and analyzed today, drawing on studies by scholars in STS, sociology, geography, environmental studies, and other fields. Although citizen science and other participatory research projects attend to topics as diverse as astronomy and nutrition, we mainly focus on participatory environmental research in this paper.

In the first part of this review, we briefly discuss different types of citizen science and introduce some theories about why such an array of participatory research practices are prevalent now. Next we turn to the many virtues of citizen science that scholars and advocates have claimed, focusing on seven that have received the most theoretical and empirical elaboration. Citizen science can enable researchers to overcome a variety of constraints on their research. It can have an educational function, expanding scientific literacy and environmental awareness. Some claim that citizen science empowers participants in a variety of ways, such as building social capital and leadership skills. Citizen science projects can level inequality between experts and laypeople and foster collaboration. Citizen science can also help social movements by filling gaps in knowledge and challenging official accounts. There are indications that citizen science can bring about policy change. It can also be used to catch polluters and bring them to justice.

Of course, no citizen science project can exhibit all seven of these virtues—particularly since some of them are contradictory. These contradictions suggest the possibility of a robust intellectual debate about which of the virtues of citizen science are most desirable and how best to encourage them. However, authors of these studies are rarely in conversation about why they value citizen science. In fact, while the literature on citizen science is very large—a recent meta-analysis identified over 2,500 articles (Kullenberg and Kasperowski 2016)—many authors appear to be arguing past each other or even unaware of the others. This may be partly due to disciplinary distinctions; ecologists, STS scholars, health researchers, and geographers are not necessarily reading each other's work.

While disciplinary boundaries are a challenge, another significant impediment to robust debate about the virtues of citizen science is an inadequate understanding of the contradictory social contexts in which citizen science takes place. Thus, in the final section of this paper we point to some dilemmas, arising from their social and political contexts, which citizen scientists are likely to face. These contexts include scientized political cultures, which may draw citizen scientists into reductive and technocratic framings of environmental problems; neocolonialism, which influences the acceptance of different forms of knowledge; and globalization, which complicates the scales at which citizen scientists mobilize. In addition, we point out that the implications of neoliberalization are poorly understood or theorized in the existing citizen science literature. Future studies of citizen science should pay attention to these different institutional and political contexts, to enrich our understanding of how citizen science enhances struggles for social change beyond making science more participatory.

Introducing Citizen Science

Definitions

Citizen science can be considered a subset of what Rebecca Lave calls "extramural knowledge production," the practice of science by people who are not affiliated with credentialed academic/research institutions (Lave 2015). Extramural science includes amateur science, crowd sourcing, citizen science, indigenous knowledge, and commercial science, among other categories.

STS researchers have generally used the term citizen science to describe the practice of science by social movement activists for the improvement of health and the environment, often in cases of environmental racism or other forms of injustice (Allen 2003; Ottinger 2013a). Alan Irwin, in his 1995 book, *Citizen Science*, described how environmental contamination was forcing lay people to learn about scientific issues and how in turn they came to contribute to science itself (Irwin 1995). A related concept is popular epidemiology, which refers to the ways that lay people collectively detect and make sense of the experience of environmental illness (Brown 1993). The concept of citizen science also has affinity with a variety of other research practices. These include participatory action research and community-based participatory research (CBPR), two approaches to research in which professional researchers collaborate with community partners to investigate and take action on a shared matter of concern (Bidwell 2009). In geography, participatory mapping enables researchers and communities to represent places on maps with features that are important to the people who live there (Elwood 2006; Bryan 2011). Finally, we also see the term citizen science applied to DIY movements that develop alternative tools for scientific research such as Genspace, a community biotech lab, DIYbio.org, X-Clinic, and Sensemakers. These projects are also often referred to as "critical making" (Ratto 2011; Wylie et al. 2014).

Outside of STS, the concept of citizen science was advanced by Rick Bonney, first to describe the contributions of birdwatchers to the science of ornithology and later in several influential articles and books with collaborators in the natural sciences (Dickinson and Bonney 2012; Bonney et al. 2014). In contrast to those who define citizen science as research by concerned and mobilized publics, researchers in this vein tend to think about "citizen science" as scientific research that employs volunteers as research assistants (Toerpe 2013). Many projects bearing the name citizen science are initiated and overseen by professional scientists, such as the researchers at the Cornell Lab of Ornithology, which compiles the observations of more than 200,000 bird-watchers each year (Trumbull et al. 2000). Using volunteer contributors to advance professional scientific research is increasingly common, seen in examples like the Milky Way project, in which volunteers look at images of the Milky Way galaxy and outline features that are of interest to astronomers (https://www.zooniverse.org/projects/povich/milky-way-project). Some citizen science of this type has been "gamified," as in the example of Foldit, an online video game in which participants solve protein folding puzzles, which helps researchers at the University of Washington to understand how living beings create the primary structure of proteins (Curtis 2015).

In this review, we focus on studies that fall under these two broad categories. At the same time, we exclude some practices that others might refer to as citizen science. The term citizen science is often used (particularly in Europe) to refer to public participation in policy or decision-making processes that involve scientific or technical matters. In this essay, we reserve the use of the term citizen science to refer to scientific knowledge production, excluding practices like consensus conferences and participatory technology assessment that do not typically involve laypeople in the scientific research process. We also exclude commercial science by private companies and the use of lay people by corporations to generate data—such as the Amazon Corporation's Mechanical Turk that uses participants to answer surveys and data collection, or what they call human intelligence tasks (HITs).

Explanations

Why have we seen such a proliferation of citizen science projects in the few decades? Amateur science has a long history, but for most of the last century amateur scientists labored in obscurity, without public recognition as a source of scientific knowledge (Vetter 2011). However, "Around 1980…extramural science suddenly experienced a dramatic resurgence in visibility in corporate, national, and international policy" (Lave 2012, 26). STS scholars have offered several different explanations for this trend. Some focus on the rise of neoliberalism, while others emphasize the impact of social movements. Another line of analysis considers the shift to a "risk society" concerned with monitoring invisible threats, while others focus on the scientization of society and politics. These explanations are not necessarily incompatible. Instead, as we discuss below, they point to simultaneous and complementary transformations occurring in many countries, which contribute to the rise of citizen science.

One explanation for the rise of citizen science is that social movements are increasingly confronting and intervening in the domains of science, technology, and medicine, forcing them to be more inclusive and participatory. Hess (2007, 47) refers to this process of transformation as *epistemic modernization*,

> the process by which the agendas, concepts, and methods of scientific research are opened up to the scrutiny, influence, and participation of users, patients, non-governmental organizations, social movements, ethnic minority groups, women, and other social groups

> that represent perspectives on knowledge that may be different from those of economic and political elites and those of mainstream scientists.

Social movements as diverse as the women's health movement, environmental justice movement, and the Black Panthers have both used and contested scientific and medical expertise in their pursuit of social change (Allen 2003; Nelson 2011; Tuana 2006). Likewise, in postcolonial contexts, social movements have challenged the oppressive and exploitative aspects of Western science, demonstrating the value of indigenous and local knowledges (Harding 1998; Escobar 1998). The increasing scrutiny of science "from below" has in some ways undermined the epistemic authority of Western science, while also making scientific institutions more democratic and open to public participation (Hess 2007; Moore 2006). Thus, social movements may be one of the forces changing scientific practices and creating greater visibility and acceptance of citizen science.

At the same time, the growing prominence of citizen science may be a consequence of neoliberal transformations to the funding and organization of science. As scientists in government and academic research institutions face cuts to public funding, citizen science becomes appealing as a low-cost way to get research done. Lave (2012) observes that citizen science, amateur science, and crowd sourcing "provide vast amounts of unpaid work for physical scientists" (28). Lave situates the "appropriation" of volunteer labor and knowledge among a contradictory set of changes to scientific institutions:

> On the one hand, commercial knowledge claims are no longer seen as potentially compromised by conflicts of interest, but instead as legitimized by market forces. On the other hand, environmental consultants have been able to establish serious scientific credibility… Citizen scientists (of the activist persuasion) are now accorded a place at the table in many regulatory decisions… and indigenous groups are consulted in developing environmental management plans…in ways that were unimaginable in the 1950s, or even in the 1970s (Lave 2012, 29).

Other cultural and political shifts aid in the growing prominence of citizen science. The ubiquity of monitoring systems—including participatory monitoring of the environment through citizen science—is symptomatic of what Ulrich Beck (1992) calls the risk society. Beck describes a society that faces the "risks and hazards systematically produced as part of modernization" by asking how "they [can] be limited and distributed away so that they neither hamper the modernization process nor exceed the limits of that which is 'tolerable'" (19). The creation of monitoring programs is a typical way that governments deal with public concern about the potential consequences of industrialization and technological change. The allure of monitoring projects derives, in part, from the invisibility of many environmental and health hazards, such as radiation and toxic pollution. Monitoring is one of the crucial tools for establishing that invisible risks actually exist. From this perspective, citizen science is a feature of a society organized around the apprehension and management of risks.

Finally, and perhaps most significantly, citizen science can also be interpreted as a symptom of the scientization of politics. At least since World War II, political decision making surrounding natural resources and environmental health has become increasingly scientized (Drori and Meyer 2006; Drori et al. 2003). Science and expertise are central to policy and regulatory processes, and public issues are typically framed as technical matters. As Phil Brown summarizes: "Science and technocratic decision making have become an increasingly dominant force in shaping public attitudes, media coverage, and most particularly social policy and regulation" (Brown 2007). Scientization has contributed to the rise of citizen science; when environmental problems are framed as matters of insufficient data, citizens are compelled to respond by creating the data to validate their concerns and to argue for remedial actions. At the same time, focusing on collecting scientific data tends to depoliticize environmental problems, reducing politico-economic problems to technical ones and obfuscating distributive and sociocultural issues. Research in STS has probed the dilemma of scientization in environmental activism and citizen science (Yearley 1992; Morello-Frosch et al. 2006; Kinchy 2012; Kimura 2016) but, as we will argue in later sections of this paper, most research on citizen science has been insufficiently critical of its implications for the framing of public issues.

Typologies

Authors have often responded to the great diversity of citizen science projects by creating typologies that highlight the myriad forms relationships between laypeople and professional scientists can take. Many of these typologies focus on the structure of participation (Lawrence 2006; Gouveia and Fonseca 2008; Bidwell 2009; Shirk et al. 2012; Haklay 2013). For example, Shirk et al. (2012) sort citizen science projects into five types, characterized by their "degree of participation." These include (among others) *contractual projects*, "where communities ask professional researchers to conduct a specific scientific investigation and report on the results," *contributory projects*, "which are generally designed by scientists and for which members of the public primarily contribute data," and *collegial contributions*, "where non-credentialed individuals conduct research independently with varying degrees of expected recognition by institutionalized science and/or professionals."

Typologies of participation often conflate the tasks completed by participants (e.g. defining questions, choosing methods, gathering data, analyzing data, communicating findings), with "empowerment." For example, some authors are critical of forms that treat participants merely as "hired hands" (Goodwin 1998) rather than aiming to empower them to effect the changes they desire. However, Lawrence (2006) observes that participation in citizen science projects that, on the surface, serve the interests of professionals can nevertheless bring about personal transformations that are empowering. Jalbert (2016, 39) finds that knowledge infrastructures for citizen science are "dynamic spaces where relationships of power are rarely settled." Thus, types or scales of participation may obscure more dynamic or contested power relations.

Some projects may be transformative for oppressed communities, without having a high degree of community participation. For instance, nonprofit advocacy organizations may carry out research that does not employ volunteers in significant ways but nevertheless provides crucial evidence of environmental harm that enables communities to fight for justice. The Southern California Environmental Justice Collaborative focuses on analyzing secondary data, particularly data collected by government agencies such as the US Environmental Protection Agency (EPA) and California regulators, in order to draw attention to environmental injustice. This approach was chosen, in part, because of the time and expense required for primary data collection and the likelihood that data collected by citizen scientists would be treated as lacking credibility. The Collaborative, a group that includes university-based researchers, thus helps environmental justice groups with "data judo," "a process in which communities marshal their own scientific expertise to conduct research and use the data in support of policy and regulatory change" (Morello-Frosch, Pastor, and Sadd 2012, 67). The academic researchers were able to produce findings that the nonprofit group could use to argue for a more stringent air quality standard. The scientific analysis helped the group to mobilize broader groups and conduct an effective media campaign and lobbying. In the end, they were able to achieve a substantial victory in changing a regional rule regarding cancer risk (Petersen et al. 2006). This case suggests that communities need not be full participants in scientific research in order to achieve environmental justice victories.

While degree and quality of participation are meaningful dimensions of citizen science, they are incomplete without attention to project goals. Wiggins and Crowston (2011) create types based in large part on project goals. They identify five main goals of citizen science: action (to support civic agendas), conservation (to support environmental stewardship), investigation (to support scientific research), investigation through virtual collaboration, and education (to support formal and informal learning). The focus on goals resonates with observations by Kinchy et al. (Kinchy, Jalbert, and Lyons 2014) about the various "logics" (consciousness-raising, policing, and scientific inquiry) that guide the actions of participatory environmental monitoring projects.

Kelly Moore (2006) focuses not on goals, but on who initiates citizen science efforts. Initiation is a crucial matter, because "initiators set agendas, the terms of debate, and define the resources, languages, and venues for discussion and adjudication available" (300). Projects may be initiated by amateur scientists, activists, or professionals, with different implications for project goals, and with varying consequences for the political authority of science.

In our view, typologies of citizen science are a useful tool for sorting out this very diverse field of activities, but whether they focus on degree of participation, goals, or initiation, typologies highlight one feature of citizen science while ignoring other dimensions that may be more significant for participants or their challengers. For example, degree of participation may be important to those who are committed to changing the institution of science, but a low priority for those dedicated to fighting for clean air and water. Furthermore, the goals of a citizen science project may be contested among the participants or change over time in response to obstacles or opportunities. A more important feature, in that case, might be the ways that citizen science teaches people skills for collaboration.

We seek to go beyond simple categories of citizen science to better understand the underlying theoretical rationales for transforming and extending the practice of science in these myriad ways. Thus, in the remainder of this review, we focus not on the types of citizen science, but on the arguments that are commonly made for the *virtues* of citizen science. In other words, we review the reasons why both advocates and analysts of citizen science contend that it is socially valuable.

Virtues of Citizen Science

In the following sections, we discuss the virtues of citizen science that have received the greatest conceptual elaboration and empirical scrutiny. The rapidly expanding literature on citizen science suggests at least seven distinctive virtues. First, from the perspective of scientists, lay participation is helpful in enlarging the size of samples inexpensively. Second, some see citizen science as a way to enhance public understanding of science. Third, many studies indicate that citizen science builds social capital, enhancing community capacity to work toward environmental goals. Fourth, advocates of democratizing science suggest that citizen science helps to build more equal relationship between scientists and citizens. Fifth, research indicates that citizen science can be useful in filling knowledge gaps and in challenging official accounts. Sixth, some see citizen science as a means to drive changes in policy. Finally, some research emphasizes the virtue of catching polluters through "neighborhood watch"-style citizen science.

(1) Increasing the Amount of Scientific Data

When professional scientists endorse citizen science, it is typically because it helps them to collect and analyze very large quantities of data. Two scientific fields, astronomy and ecology, have made extensive use of citizen science as a method of data gathering in recent years. Citizen ecologists are of particular interest in this paper because of their contributions to environmental knowledge. Citizen science is often seen as enabling professional ecologists to carry out research that otherwise would be extremely difficult or expensive to carry out because of the spatial scale of the phenomenon in question. A recent review article claims:

> Citizen science is perhaps the only practical way to achieve the geographic reach required to document ecological patterns and address ecological questions at scales relevant to species range shifts, patterns of migration, spread of infectious disease, broad-scale population trends, and impacts of environmental processes like landscape and climate change (Dickinson, Zuckerberg, and Bonter 2010, 166).

The difficulty of carrying out such research without the help of volunteers stems not only from the geographic scale of the work, but also from budgetary constraints. Discussions about citizen science in the field of ecology frequently draw attention to the expense of research, as in one study on the prediction of emerging plant diseases, which indicates that "the economic cost of collecting sufficient data …is often prohibitive but may be offset by involving volunteer citizen scientists in the data collection process" (Meentemeyer et al. 2015, 189). One report on biomonitoring in a Canadian biosphere reserve begins by bluntly stating that the need for community participation arose from "concern over government's ability to monitor ecosystems in light of severe cutbacks in environmental programs" and "government's inability alone to carry out monitoring to address the complex and emerging environmental and sustainability issues of the day" (Craig and Whitelaw 2003).

There has been little research in STS or by other social scientists about this claimed virtue of citizen science. Rebecca Lave (2012) characterizes such projects as using "unpaid labor" to advance the research agendas of professional scientists, highlighting one project that "is supported by volunteers who not only pay fees to participate, but also contribute an estimated $3 million per year in unpaid labor" (Lave 2012, 28). Indeed, scientists are often explicit about their use of volunteers in order to make up for insufficient public funding for important ecological research. Unpaid labor makes crucial research possible—which is a virtue from the perspective of the ecologist—by shifting the burden of supporting such research from the public (e.g. the National Science Foundation) to private volunteers.

Little is known about volunteers' perspectives on the use of their unpaid labor. Studies (discussed below) have considered educational outcomes, changes in environmental attitudes, and other benefits of participation, but have not asked how citizen scientists feel about providing unpaid work to projects led by paid professionals. Ecologists writing about citizen science rarely mention the fairness of the labor arrangements. In general, it seems to be assumed that participants want to do the work because they are "outdoor hobbyists" who value the research objectives and enjoy the activities they are called upon to do. Research by STS scholars Ellis and Waterton (2004), however, paint a more complex picture. In the United Kingdom, amateur naturalists have been recruited into a policy initiative to know and record biodiversity. The volunteers who observe and record information about plant and animal species feel passionate commitment to the work, yet are conflicted about the ends to which is it put. Ellis and Waterton (2004, 99) explain:

> Some, but not all, naturalists perceive the way in which the policy domain acquires data as predominantly extractive, which leaves open to question the extent to which data contributors feel adequately recompensed for their contribution. Most recently, increased commodification of biological records, combined with the selective payment of some data compilers and processors (consultants) and the assumption that data from naturalists generally require no financial recompense, has fuelled heated debate both within societies and between the volunteer and professional domains.

Ellis and Waterton (2004) describe one woman's feelings when "she notices that her data are being used more to raise the profile of a set of conservation professionals than for 'real' conservation. On a daily basis, Judith seeks to reconcile her passion for observing and knowing nature with these sad reflections" (99).

Citizen science enables important research on pressing issues relating to climate change, disease, and species extinction, among others. However, appreciation of this virtue raises larger questions about the science funding regime and the sharing of benefits arising from volunteer labor.

(2) Expanding Scientific Literacy and Environmental Awareness

Many advocates contend that participation in citizen science increases scientific literacy and makes people more aware of environmental problems and ecological systems. Educational outcomes are the most frequently studied effect of citizen science projects, according to one meta-analysis of the literature (Stepenuck and Green 2015). Most studies, unsurprisingly, show that citizen scientists learn content knowledge about the subject they are studying, although if participants who elect to join a project already have high levels of science education, such gains may not occur (Overdevest, Orr, and Stepenuck 2004). Some studies suggest that participants also gain skills related to the process of environmental monitoring, as well as skills for communicating findings (Stedman et al. 2009). There is also research to suggest that participants gain understanding of ecological processes, which may change their assumptions about environmental issues (Fernandez-Gimenez 2008).

The research on learning through citizen science not only addresses individual knowledge acquisition, but also "social learning," which refers to "an intentional process of collective self-reflection through interaction and dialog among diverse participants" (Fernandez-Gimenez 2008). Social learning is theorized to promote better understanding of the effects of management decisions and policies, as well as reflection on assumptions and values that underpin actions. One study of 13 community-based forestry projects found some evidence of social learning; for example, working with other volunteers with different perspectives and applying their research to questions about environmental management decisions led people to change their beliefs and perspectives about the forests (Fernandez-Gimenez 2008).

The emphasis on education as a virtue appears to be based on an assumption that when people learn about the environment, they will become better stewards of natural resources. Toomey and Domroese (2013) test this assumption, positing a relationship between participation in citizen science and resultant effects on personal conservation attitudes and behaviors. They describe:

> a cycle or feedback loop in which participation itself leads to the perception of having done something positive for the environment ("greener sense of self"), thus leading to more positive attitudes towards conservation behaviors in general, reinforcing motivations that led the participants to join the project in the first place. In part, this is promoted through increases in environmental knowledge and awareness, as a result of having learned something new or learned in a new way through a scientific lens or direct experience (52).

Toomey and Domroese (2013) found that participants came to projects with already high levels of concern for the environment, but their concern nevertheless increased as a result of participation. Effects on behavior were less clear, however. The citizen science projects did not offer clear links to conservation behaviors or advocacy. Participants indicated their interest in sharing their knowledge and in continuing their environmental monitoring work. However, “there was an otherwise weak inclination for volunteers to translate their experiences into advocacy or environmental stewardship” (Toomey and Domroese 2013, 59). These findings call into question the notion that education and learning will lead to improved environmental stewardship. Citizen science projects may well be teaching people science—a virtue in its own right—but they are not necessarily teaching the citizenship skills needed to advocate for environmental policy.

(3) Building Social Capital and Community Leadership

Some advocates of citizen science emphasize the ways that participation can help communities to build capabilities to participate in conservation. Social science research has provided some support for this claim. Stedman et al. (2009, 178) found that watershed organizations in the US state of Pennsylvania were “effective mechanisms for building local leadership, enhancing the skills of rural residents, and making valuable connections with other communities, facing similar water-resource and rural-development issues.” Likewise, Overdevest et al. (2004, 183) found that experienced participants in a watershed monitoring project “were more active than their inexperienced counterparts in resource management-related behaviors, such as talking with and providing information to neighbors about resource issues, engaging in personal reading and research about resource issues, and attending public meetings to discuss issues.” Their findings led them to speculate that similar programs could generate a “more engaged and connected citizenry,” with the important caveat that participants in their study tended to be highly educated and high income (183).

Numerous other studies present evidence that participation in citizen science builds “social capital” (Stepenuck and Green 2015; Wagner and Fernandez-Gimenez 2008; Floress, Prokopy, and Allred 2011; Nerbonne and Nelson 2004). Social capital is typically conceptualized as trust, norms of reciprocity, and social networks that enable a community to collectively solve problems. Research in this vein commonly borrows ideas from the literature on voluntary associations, civic participation, and democracy (for an overview, see Fung 2003). Scholars in this area generally agree that participation in voluntary associations strengthens democracy, but they disagree about how and why volunteering has positive effects. Most of the research on citizen science and social capital draws on the Tocquevillian tradition (Putnam 2000) emphasizing that sustained participation in volunteer groups, like watershed monitoring teams, enables people to gain skills, knowledge, relationships, and mutual trust that are necessary for participation in democratic life. Many citizen science projects have been shown to have these virtues.

There is a great deal of citizen science research that emphasizes its contributions to social capital. However, some social scientists are skeptical that all kinds of voluntary participation strengthen democracy. These scholars ask what kinds of associations enable people to confront the roots of inequality and injustice that threaten democracy (Eliasoph and Lichterman 2010; Szasz 1992). For example, some associations “create avenues for direct participation in the regulation or production of public goods such as education, public safety, and the provision of social welfare” (Fung 2003, 516). Some environmental monitoring groups provide services that might not otherwise be provided by the state or the market, thus, perhaps, deepening engagement in crucial aspects of public life. Other kinds of volunteer organizations are what Fung (2003) refers to as "mischievous" associations—those that facilitate disruptive social movements that challenge powerful actors. Citizen science that is mischievous may be necessary when social inequality weakens democratic decision making. We see greater attention to these forms of civic participation in studies that consider the problem of inequality between experts and laypeople, and examples of oppositional citizen science, discussed in the next two sections.

(4) Leveling Inequality between Experts and Laypeople and Fostering Collaboration

While many emphasize the virtue of building social capital within communities, others emphasize the positive effects of making science more inclusive and leveling status distinctions between experts and the lay public (Soleri et al. 2016). Most of the typologies of participation discussed earlier focus on this virtue of citizen science. In their review of voluntary water monitoring in the US, Pfeffer and Wagenet argue, "Volunteerism is a form of grassroots environmental activism that to some extent furthers the ideals of democratic participation and establishes a basis for direct interactions between citizens and scientists… We conclude that volunteer monitoring is a useful practice for reducing the chasm between citizens and scientists and is one useful way to link humans and their environment" (Pfeffer and Wagenet 2007, 246). However, they also note that volunteer-generated data can face skepticism from scientists, suggesting that citizen scientists are not regarded as equally credible knowledge producers.

As described above, the fields of conservation and ecology have embraced citizen science, and in some cases this has meant flattening the expert-citizen relationship. For instance, at the Coweeta Hydrologic Laboratory in North Carolina, one of the most established research stations on forested watersheds in the US since the 1930s, Heynen and his collaborators started the Coweeta Listening Project (Burke and Heynen 2014). Their motivation was to move away from the dominant ecological research at the site, which they see as conceptualizing people "as agents of ecological disturbance, impediments to precise experimental controls, or, more recently, as research subjects in need of explanation" (8). In contrast, the project they started aimed "to connect scientists and nonscientists in more democratic and mutually beneficial relationships of ecological knowledge production and use" (Burke and Heynen 2014, 8). Drawing on political ecology, feminist, and Gramscian theoretical frameworks, the central motivation for citizen involvement is to challenge knowledge hierarchies by institutionalizing dialogues with community organizations to identify areas of concern. They report:

> Through the CLP we have sought to establish the preconditions for popular education by organizing "translational dialogues" within western North Carolina. These dialogues are open discussions hosted by community organizations, facilitated by us to prioritize place-based concerns and knowledge, and enroll Coweeta LTER ecologists as both listeners and contributors. Translational dialogues seek to highlight the value of place-based knowledge, alter traditional expert-lay and lecturer-audience dynamics, and introduce socioenvironmental issues into the public realm. Participants in these dialogues often struggle to abandon dominant knowledge hierarchies and honestly consider the potential

> insights from multiple forms of knowledge. However, we are encouraged that both scientists and nonscientists have noted that these engagements open their eyes to new questions and considerations, and that translational dialogues have helped us build longer-term partnerships with two community groups studying possibilities for local climate change adaptation, which has allowed us to advance further through the cycle of learning and action (Burke and Heynen 2014, 18).

Challenges to the traditional expert-citizen hierarchy have also been valued in participatory mapping and open source mapping movements. For instance, OpenStreetMap (OSM), started in 2004 in Europe, aims to provide a free digital map where citizens can contribute updates and revisions of their local geographic data on a user-friendly online platform. They also have localized meetings dubbed mapping parties to discuss localized contents (Haklay, Singleton, and Parker 2008; Haklay 2010). The point of making an open-source map lies is not simply in accumulating data, but in making maps that are in the public domain and help empower lay users to access and modify maps.

Some observers question whether formalizing the inclusion of lay participants in scientific research projects is beneficial to social movements. West Harlem Environmental Action (WE ACT) began as a grassroots struggle against a sewage treatment plant that was causing health problems for neighborhood residents. Over time, and with a major legal settlement, WE ACT became a stabilized organization with a large "infrastructure of environmental justice programs" and partnerships with the Columbia University School of Public Health (Moore 2006). Moore (2006, 306-307) argues that "the institutionalization of [programs like WE ACT] makes nonscientists' experiences and evidence more important in problem solving and in the creation of general scientific knowledge." However, there may be drawbacks to formalizing the participation of laypeople. Moore (2006) notes that "gaining a seat at the table of science may also mean that nonscientists lose the leverage that their specifically political and moral claims once allowed them." Citizen science might inadvertently diminish participants' roles as activists and social movement organizers.

(5) Challenging Authority

While some observers focus on the ways that citizen science generates more equitable and cooperative relationships between experts and laypeople, others emphasize how citizen science can be oppositional (or mischievous) (Ottinger 2016; Brown 2007). Citizen science can be a tool to support social justice struggles by challenging denials of environmental health problems. In the United States, for example, the environmental justice movement has strategically aligned with scientists and gathered environmental health data, while at the same time identifying social inequities and unjust institutions as the target of the broader struggle (Bullard 2005). For instance, in Love Canal, NY, local home residents mapped birth defects and illnesses in their neighborhood to provide proof of the health effects of chemicals underground left by a chemical corporation (Blum 2008).

More recent examples of this line of work can be found in Norco, Louisiana, where African American local residents complained of various health ailments and protested the Shell

Corporation. They contended that the ambient data gathered by the Louisiana Department of Environmental Quality and EPA only measured the average concentration of toxic chemicals over time and did not capture sudden spikes during and immediately after the release from the factory. Local groups such as Louisiana Bucket Brigade trained local residents to deploy a simple air-sampling method that enables them to send plastic bags of suspected air pollution to a laboratory for chemical concentration analysis. Their data convinced government regulators to investigate further (Ottinger 2010b).

The same network, Louisiana Bucket Brigade, also became active in the aftermath of the Deep Horizon oil spill in 2010, trying to uncover the extent of the damages that might not have been captured by the government agencies and the responsible corporate actors. The group crowd-sourced pollution data and created the Oil Spill Crisis Response Map. Regular citizens input exposure data using its website or cell phone. The Crisis Response Map covered a broader range of issues than the government agencies, allowing citizens to add data including odor, oil on water, properties damaged by oil, and impacts on wildlife and birds. The Map also covered broader geographic areas than the government monitoring (McCormick 2012).

Out of the collaborative mapping response to the BP disaster arose Public Lab (PublicLab.org), a network of groups and individuals that create and share hardware and software virtually to address local environmental issues (Wylie et al. 2014). Wylie et al. (2014) discuss Public Lab as an example of challenging the traditional expert-citizen hierarchy: citizens are collaborators, not merely data collectors, because they are involved in setting research questions and solving problems (see also Breen et al. 2015). The Public Lab's mapping contrasts with conventional map making by governments and corporations that typically employs a "God's Eye view" (Wylie et al. 2014, 121). The maps made by citizens—an example of what they call "civic technoscience"—help "change science's material, social, and literary technologies in a way that stabilizes new strategic spaces for critique of science."

The production of data that is missing from mainstream science was similarly a driver for a project by urban farming organizations in New York City where they faced the need to collect data on agricultural yields and economic potential of community gardens. The mayor decided to enable the sales of the gardens to private interests and the urban farming organizations had to produce data that captured the value of community gardens. A non-profit organization called Farming Concrete developed an open source platform (now called Farming Concrete Data Collection Toolkit) where diverse community garden organizations could input data regarding their production structures, types, volumes and other relevant information. Farming Concrete was able to show the city officials their substantial contribution to the city's food security and economic well-being (Gittleman, Jordan, and Brelsford 2012).

Observers of these and other examples draw attention to the virtue of confronting official neglect of issues that are important to social movements (Ottinger 2013b; Frickel 2008; Hess 2015; Frickel et al. 2009). Citizen science can challenge official accounts to address broader environmental injustices. This virtue is different from the first one (adding data) because here citizen science does not just produce knowledge about pollution; it also challenges authority and supports processes of collective mobilization for contentious politics (Minkler et al. 2008b; Corburn 2005).

(6) Driving Policy Change

Some writings about citizen science emphasize policy relevance as a virtue. Knowledge produced by citizen scientists can support arguments for changing public policy and regulatory strategies. Corburn (2005) describes a case in which the EPA initiated a study to model cumulative exposure to toxic pollutants in the Greenpoint/Williamsburg neighborhood of Brooklyn, New York. Although the project did not begin with a plan for public participation, a first step in the project was to hold community meetings in order to consult with residents. Through those meetings, the EPA learned that the agency was overlooking a major dietary risk: the consumption of fish caught from the East River. Initially skeptical of the community's concerns about fish consumption, the EPA worked with a community organization, The Watchperson Project, to learn more about this potential risk. EPA helped the Watchperson Project to gather data from anglers and ultimately used those findings in its calculations of lifetime cancer risks and recommendations about fish consumption (Corburn 2005, 94-109).

Jill Harrison's research on pesticide drift movements examined a citizen science project led by an environmental NGO, the Pesticide Action Network North America (PANNA). PANNA scientists developed a device called a Drift Catcher, which pumps in the air to collect a sample that is then analyzed in a professional laboratory. The difficulty of correctly maneuvering the device as well as the frequency and duration involved was a challenge to volunteers, many of whom were low income and non-English native speakers. When the PANNA scientists returned the results to community members, data interpretation and presentation was also frequently difficult for participants. Despite these challenges, some communities were able to press for new county level regulations such as buffer zones around schools and houses in California and to lobby for funding for the state government's air quality monitoring for pesticides in Washington (Harrison 2011).

Some research has attempted to identify the features of citizen science that lead to successful policy changes. Summarizing participatory research projects by environmental justice organizations in four different areas covering diverse issues from lead poisoning to air pollution, Minkler et al. (2008a) found that data collection with academic institutions enabled these organizations to achieve substantial public policy outcomes. They found that organizations with community and partnership capacities (leadership, participation, resources, skills, network, sense of community, shared values, critical reflection, understanding of community history) are more likely than those organizations without these capacities to achieve policy changes.

(7) Catching Polluters and Bringing them to Justice

If some emphasize interventions through challenging authority or promoting policy change, others focus on the virtue of catching polluters in the act of breaking environmental rules. Overdevest and colleagues (Overdevest, Orr, and Stepenuck 2004) use the example of "observers who monitor for Clean Water Act violations on industrial timber harvests in the southern US" as an example of this type of citizen science. There are numerous examples of citizen scientists, particularly in the case of air quality monitoring, drawing attention to regulatory violations (O'Rourke and Macey 2003; Ottinger 2010b). Some researchers have drawn explicit comparisons between citizen science and the practices of community policing, such as neighborhood watch efforts in high-crime areas (O'Rourke and Macey 2003; Lynch and Stretesky 2013). Another analogy would be to the increasingly common practice of capturing police encounters on cell phone video, to serve as evidence of abusive or illegal uses of force (Brucato 2015).

Although there are several case studies showing that some citizen science projects aim to improve the enforcement of environmental laws, there have not been systematic studies of the effectiveness of citizen science for this purpose. Surveys of organizations that do volunteer water monitoring suggest that environmental policing is not a major aim of these projects, compared to the more prevalent goal of raising environmental awareness (Nerbonne and Nelson 2004; Nerbonne and Nelson 2008). However, in a study of citizen scientists who are tracking the impacts of the natural gas industry on watersheds in Pennsylvania, Kinchy et al. (2014) find that a "policing logic" guides the work of some monitoring groups. The volunteers test water samples on a regular basis and report any signs of pollution or disturbance (such as stream bank erosion) to regulatory authorities. Some refer to themselves as extra "eyes and ears" for state regulators. Others, using sensors to accurately track changes in water quality on a continuous basis, hope that their data will stand up to scrutiny in a court of law. It remains unclear, however, how much these efforts have improved the enforcement of environmental law (Jalbert and Kinchy 2015).

Contexts of Citizen Science

The literature on citizen science has emphasized a range of scientific, educational, administrative, policy, and social movement-related virtues. It is important to reiterate here that we have not described "types" of citizen science, for, indeed, a single project may be described as having several of these virtues. Instead, the above discussion lays out the various claims that have been made about the societal contributions of citizen science.

We observe that research on citizen science often emphasizes certain virtues while overlooking or downplaying others. For instance, in a study of residents near a Superfund site, the authors interpreted gardeners' efforts to gather data on soil contamination as a case of doing science that is relevant to the daily lives of regular people (Ramirez-Andreotta et al. 2015). The authors characterized the programs as an example of excellent risk communication that helped citizens understand the relative risk of contaminants and decide the usage of home gardens. This interpretation seems to assume a social context in which exposure to contaminated soil is a matter of homeowner choice. However, an observer who views this case in the context of urban deindustrialization and regulatory neglect might contend that the larger virtue of citizen science is that it led some of the residents to become interested in legislative and policy actions—a virtue that the authors only mention in passing toward the end of the paper. This example illustrates the importance of situating citizen science in the broader social context in which it takes place.

There are contradictions among the various virtues of citizen science. For example, amassing large datasets for academic research is largely incompatible with catching polluters or leveling inequality between experts and laypeople. We also observe that a virtue from one perspective might be a drawback from others. For instance, while some might praise citizen science for enabling research to go on even in the face of neoliberal funding cuts, a more critical perspective might suggest that citizen science helps to justify such a political milieu, ultimately undermining the conditions needed to support academic and government science. Likewise, while citizen science can be admired for increasing environmental awareness among participants, critics might argue that citizen science channels public concern about the impacts of industrial developments toward scientific and technical questions rather than the socio-political roots of environmental problems.

In an insightful essay entitled "Citizen science and scientific citizenship: same words, different meanings?" Alan Irwin (2015) observed the heterogeneity of citizen science and argued the importance of asking questions about citizenship. Citizen science can be a means for performing and developing citizenship, but he also noted that "this cannot be taken for granted and is by no means given—sometimes (just as Freud may have said about cigars) a project about earthworms is just a project about earthworms" (10). The heterogeneous mix of citizen science projects and their ambiguous relationship with justice prompted him to ask, "Is citizen science only about producing more science in nonconventional ways? Or does it have a larger role in terms of these citizenship questions?" (6).

Answers to these questions, we argue, will depend upon broader socio-political and economic contexts. For example, virtues of self-help, science literacy, and education may be key to survival in oppressive political regimes, where communities have few opportunities to effect political change. At the same time, projects advancing self-help and localized problem solving might actually exacerbate processes of neoliberalization, further undermining the regulatory state. Likewise, in contexts where environmental activists gain little traction unless they justify policy positions with scientific data, there is good reason to expand citizen science initiatives that produce policy-relevant knowledge. However, in the context of a growing environmental justice movement, citizen science that focuses on amassing regulatory-quality data may pull people away from direct challenges to politico-economic elites.

These tensions and contradictions cannot be understood apart from the social contexts in which citizen science takes shape. For this reason, we take issue with studies of citizen science that rate particular projects on their degree of participation or other virtues that are presumed to be inherent to the design of the project itself. We find greater value in research that seeks to understand how citizen scientists contend with the contradictory pressures and demands that they face in order to produce the outcomes they seek.

Here we highlight research that makes connections between citizen science and its social context, with a focus on several aspects of social structure: 1) scientism in governance and media, 2) the legacy of colonialism and neo-colonial incursions, 3) the globalization of trade and governance, and 4) processes of neoliberalization.

Scientization

Scientism refers to the societal privileging of credentialed science as the only legitimate source of knowledge upon which to base policy and institutional decision making, and the process of its expansion is referred to as scientization. In our own research, we noted scientization's stifling effects on citizens' collective mobilizations, as it tends to depoliticize complex social issues (Kimura 2013; Kinchy 2012). Welsh and Wynne also observed that when social movements point out normative choices involved in scientized discourse, they tend to be critiqued as anti-science (Welsh and Wynne 2013).

Some scholars of citizen science have noted how scientization can diminish the power of communities fighting for environmental justice. For example, Fabiana Li (2015) examines the work of organizations that encouraged participatory water monitoring in mining communities in Peru. The impetus for monitoring came not only from NGOs but also from the mining industry (which wanted to establish baseline data that might enable them to argue that water had always been of poor quality in the region) as well as international funding agencies. She points out:

> science and risk assessment often come to replace larger concerns around mining expansion. This process shifts the focus from social, political, and ethical concerns to scientific studies of environmental impacts and technological solutions…the participatory nature of endeavors such as water monitoring could not conceal the evident tensions and divisions that plagued the Mesa since its inception (104).

Li's research suggests that citizen science is likely not an effective way to stand up to a powerful industry if the questions of concern are reduced to technical matters. By framing the issue of mining as one that can be adjudicated through scientific data collection, rather than claims for rights, justice, local sovereignty, or other values, citizen science can make activists vulnerable to attacks by opposing experts.

David Pellow (1997) makes a similar point in a study of a grassroots environmental organization in Chicago that conducted a health survey in a low-income community and identified air pollution as a frequent cause of illness. The EPA responded by saying they would need to see stronger evidence, so the organization convinced university public health researchers to carry out a more scientifically sophisticated health study. This second study convinced the EPA to begin an initiative to reduce pollution in the area. Pellow observes that the case could be interpreted as an example of community empowerment through participatory research. However, he notes that it could equally be interpreted as community disempowerment, because the activist group was subordinated to scientific experts. The historical, political, and economic experience of environmental injustice was "reframed in the form of scientific documentation, mostly devoid of any sense of conflict or oppression" (Pellow 1997, 319). In a context where regulatory agencies will only respond to scientific data, rather than a community's widely-held knowledge of environmental illness, it may be necessary to present grievances in the form of scientific data, but this devalues the knowledge of non-scientists and minimizes questions of social justice.

Pellow's (1997) study concluded that popular epidemiology (citizen health science) was "both costly and beneficial, empowering and disempowering" (319). We observe such contradictory processes in many cases of citizen science, where the scientization of environmental politics pressures activists to reframe their concerns in terms of technical rationality and data.

(Neo)colonialism

Citizen science needs to be situated in a broader context of colonialism and its continuing legacy, particularly in the Global South but also in relation to indigenous peoples worldwide. Is the knowledge produced by citizen scientists commensurable with the language of mainstream science and/or regulatory science used by governance organizations? To what degree are citizen scientists free to decide the kinds of data they collect? The impacts of scientization, discussed above, are mediated by historic patterns of inequality that we would like to capture with the term (neo)colonialism.

Participatory mapping has become an important tool for indigenous communities in claiming their territorial and other resource rights. While participatory mapping is useful and often legally required to secure indigenous claims, it is not simply about adding locally derived data to the basic geographic coordinate system. Joe Bryan (2009), who researches participatory mapping by indigenous communities in Latin America, argues:

> Mapping lands from an indigenous perspective in order to counter colonial patterns of exclusion also opens up the possibility for new forms of assimilation. Like indigenous knowledge more broadly, the perceived usefulness and validity of indigenous maps is often a function of their ability to contribute to the kinds of "universal" knowledge organized by the natural and social sciences that forms the basis for modern forms of governance. Nowhere is this more evident than with the growing use of mapping in rolling out decentralized models of development and conservation. Throughout, old inequalities are often re-inscribed through recognition of indigenous rights, raising any number of immediate concerns for the future of indigenous mapping (25).

Bryan's comment highlights how indigenous communities may find both enabling and disabling effects of mapping. On the one hand, indigenous knowledge mapped with GIS helps their claims on territory and resources. On the other hand, the mapping exercise that only logs what is deemed important from a Western perspective falls short of holistic recognition of their identity and history.

A similar tension was identified by the Hi'iaka Working Group (2011), which summarized an NSF-funded workshop on indigenous ecological knowledge and GIS in the US. The workshop acknowledged the value of GIS for indigenous communities but highlighted tensions between GIS and indigenous knowledges. The authors noted that "current geospatial techniques and technologies have limited potential to represent Indigenous cultural knowledge and may have detrimental effects because they deemphasize, ignore, or devalue concepts that are of central importance Indigenous cultures" (242). From this perspective, currently dominant map making platforms fall short of addressing characteristics that are of importance to native peoples, including "connectedness and relationships," the "ability to move back and forth through time and across space", and "beliefs in nonhuman persons in the landscape" (245).

Such tensions can be understood as questions of epistemological justice: whose knowledge gets defined as legitimate? Citizen scientists from communities with alternative epistemologies would have to navigate the benefits of using Western scientific frameworks and technologies and the possible drawbacks of misrepresentation and marginalization of alternative and unique ways of knowing.

Globalization

Citizen science needs to be situated in the broader context of globalization. Citizen scientists may confront problems that transcend multiple ecological and political scales. For instance, natural gas emissions from faulty infrastructure may be measured locally as air pollution or at a planetary scale using satellite imaging. The company responsible for the emissions may be headquartered in another country, and authority to reign in the emissions may not be located in local or state agencies, but instead national government or even international treaties. To address problems of this sort, citizen scientists must be prepared to challenge the transnational locus of power—be it multinational corporations, international trade agreements, or transnational scientific bodies—as well as grapple with the transboundary movement of pollutants. Citizen scientists inhabit multi-scale political environments that require different modes of claims-making and collective action. The localist and DIY inclinations in some citizen science projects may be incompatible with the global loci of politico-economic powers.

Environmental movements in the Global South have often effectively evoked global environmental discourses (Rothman and Oliver 1999; Zavestoski 2009; Carruthers 2007; Urkidi and Walter 2011) and created cross-national alliances to challenge a shared target, such as transnational corporations (Urkidi and Walter 2011). Citizens have also sought assistance from experts in other countries. For instance, in Mexico, indigenous activists and peasant organizations partnered with transnational NGOs to analyze samples of maize. They reported their discovery of unregulated genetically engineered material to activists and concerned scientists, bringing worldwide attention to their concerns (Kinchy 2012). Framing local issues in a globally relevant manner (that is, using the languages of Western science and frames of international NGOs and governments) may be one of the few effective ways to challenge transnational capital and to forge international solidarity among other impacted communities. But it poses the dilemma of reducing the problem to a common denominator at the expense of more locally rooted understandings of the problem and solutions.

If pollution and degradation is globalized, environmental governance is also globalized and this poses another dilemma for citizen scientists. Environmental governance in developing countries is often mediated by supra-national organizations such as the World Bank. Since the 1990s, these organizations have increasingly adopted public consultation and citizen participation practices. While some observers welcome this move as a democratization of international development, others have critiqued it as a mechanism of co-optation and window dressing when the fundamental parameters of conservation/development are not up for challenges by local groups and are rooted in a neoliberal model of development (Cooke and Kothari 2001). For instance, Finly-Brook (2007) analyzes the Mesoamerican Biological Corridor (MBC) funded by the World Bank, UN organizations, and bilateral donor agencies such as USAID. MBC was heralded as a participatory development project, involving communities in mapping and other activities. However, Finely-Brook (2007) points out that "the MBC has been touted as participatory, but Nicaraguan findings suggest a limited role in decision making on the part of local governments and impacted populations. Proposed development projects in corridors would more often stimulate resource marketing and future donor lending rather than strengthening biodiversity protection" (101). Furthermore, "with its focus on civic participation, poverty reduction, biodiversity protection and green spaces, the MBC is expected to help diffuse criticisms" of free trade deals (103). Participation in the project might have helped local communities to stake out their interests and claim benefits from conservation projects while at the same time facilitating the model of "green growth" pursued by the World Bank and other development organizations. In such contexts, globalization presents a profound dilemma for local communities; they may participate with the hope that it will improve their livelihoods, while being co-opted to lend legitimacy to development policies that are not of their making.

Neoliberalism

STS has yet to analyze the full implications of neoliberalization on citizen science. The interests of scientists and regulatory authorities in citizen science have increased partly due to neoliberal funding cuts since the 1980s. Citizen science might facilitate this trend by effectively outsourcing monitoring and other functions to lay (often unpaid) citizens (Lave 2012). Some scholars have interpreted citizen science as a kind of resistance to neoliberalization. For instance, Burke and Heynen (2014, 8) observe that the neoliberalization of nature and science structures "knowledge production and environmental governance in a manner that further restricts popular participation." They regard citizen science as a countervailing force to this trend. However, we observe that citizen science can also re-enact the neoliberal insistence on market mechanisms, regulatory devolution, and public funding cuts to its influence on citizens' subjectivity, creating the docile, self-responsible "entrepreneur of himself" (Foucault 2008, 228).

The literature on volunteerism under neoliberalism suggests that the turn to affective and free labor by regular citizens in the name of harnessing civil society is a salient feature of neoliberalization (Muehlebach 2012). Volunteerism is often conceived of as service provision, rather than collective mobilization, while the latter is stigmatized as too disruptive, unproductive, and idealistic. The citizen scientists found in the STS literature tend to be the "mischievous" type, activists who use citizen science to collectively challenge racism and politico-economic powers (Allen 2003; McCormick, Brown, and Zavestoski 2003; Brown et al. 2003; Ottinger 2010b). But citizen scientists who take environmental and health issues into their own hands also frequently fit the neoliberal model of rational, capacious and self-responsible citizens (Ottinger 2010a).

Neoliberalism's profound impact has been observed in research by Liévanos et al. (2011) on citizen participation in the science of pesticide drift in California. They noted that regulatory scientists in the state EPA might collaborate with citizens but they were ultimately constrained by "the diffusion of neoliberalism into pesticide regulation to make it increasingly characterized by weakening regulatory coercive power and resources in favor of more voluntary, market-based solutions to environmental conflict" (202). Neoliberalism exerted its influence in the form of a particular subjectivity as well. They wrote, "while street science is typically associated with collective action and empowered citizenship, it is coupled here with techniques, especially biomonitoring, that tend to individualize environmental hazards and emphasize self-care as a key component of citizenship" (224). Future STS research on citizen science will need to contend with the ways that neoliberalization shapes funding and policy processes, as well as the subjectivities of participants.

Conclusion

STS scholarship on citizen science has shed light on how citizen scientists raise environmental consciousness, supplement works by credentialed scientists by enlarging the supply of data, and publicize local knowledges of ecologies and communities. STS scholars have also explored how citizen science might be used to challenge accounts produced by credentialed experts, shift media and policy discourses, and drive policy changes. It is important for STS to examine changing scientific cultures and practices, and this includes the increasing promotion and visibility of citizen science, both within and external to traditional scientific institutions.

In STS, research on citizen science has often focused on the question of lay-expert hierarchies and boundaries; participation in science is thus the main theme. Our aim has been to look more broadly at the array of citizen science virtues that observers and practitioners have claimed. The result has been to decenter participation as the sole or primary virtue of citizen science, bringing to light other claims about its benefits to society. This approach enabled us to observe the interpretive frameworks that analysts bring to their work on citizen science. One of the key reasons why it is difficult to generalize about the virtues of citizen science is that different virtues will be more salient depending on the political context. Our hope is that this paper will serve as a starting point for a robust intellectual and public debate about the reasons for dedicating time and resources to citizen science and the values that inform these projects.

Our review of this literature also led us to identify contradictions and tensions that are often obscured in efforts to sort citizen science into types. Specifically, we observed that the pursuit of some virtues may have undesirable implications. Citizen science may fill knowledge gaps and empower lay people to participate in environmental science controversies; yet these very efforts may smooth the way for deeper cuts to science funding or marginalize environmental claims that are not reducible to scientific data. These observations led us to examine more deeply the contexts of citizen science. Research that grapples with unwanted or ambiguous outcomes has interpreted such effects as stemming from broader social processes of scientization, (neo)colonialism, globalization, and neoliberalization. Future STS research should build on these insights and better contextualize citizen science. While the literature on this topic is growing, there remains a need for more analysis of the social and political forces that create dilemmas for citizen scientists.

Understanding what citizen science can achieve within broader political contexts is a key challenge for both STS scholars and practitioners of participatory environmental research. A robust framework for the analysis of citizen science will not only address the ways scientific data is collected and put to a particular use; it will also situate the project in relation to broader social structural forces.

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